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TRANSACTIONS

OF THE

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TRANSACTIONS

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Mr W. E. AGAR's Paper, "The Development of the Skull and Visceral Arches in *Lepidosiren* and *Protopterus*."

ERRATA.

Page 51, lines 16–19, *read* "Behind this shelf three nerve trunks pass over the trabecula, the superior maxillary branch of the fifth nerve (v.^{2}, figs. 7 and 13), the inferior maxillary branch of the fifth nerve (v.^{3}, figs. 7 and 13), and the buccal + superficial ophthalmic branches of the seventh nerve."

Page 56, line 13, *for* "v.^{2} from v.^{3}, vii. lateralis," *read* "v.^{2}, v.^{3} from vii. lateralis."

Plate II., fig. 7, and Plate III., fig. 13, *for* "v.^{3}, vii. lat.," *read* "v.^{3}," and *add another arrow for* "vii. lat."

Plate III., fig. 15, *for* "v.^{2}" *read* "v.^{2}, v.^{3}," and *for* "v.^{3}, vii. lat." *read* "vii. lat."

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TRANSACTIONS.

I.—Elimination in the case of Equality of Fractions whose Numerators and Denominators are Linear Functions of the Variables. By Thomas Muir, LL.D.

(MS. received November 6, 1905. Read same date. Issued separately January 6, 1906.)

(1) It is well known that if equations of the type referred to in the title be dealt with like ordinary quadrics, the eliminant obtained is marred by association with an irrelevant factor. Thus, to take the simplest case, viz.

$$\frac{a_1x + b_1y}{\alpha_1x + \beta_1y} = \frac{a_2x + b_2y}{\alpha_2x + \beta_2y} = \frac{a_3x + b_3y}{\alpha_3x + \beta_3y},$$

or

$$\left.\begin{aligned} |a_1a_2|x^2 + \{|a_1\beta_2| + |b_1a_2|\}xy + |b_1\beta_2|y^2 = 0 \\ |a_2a_3|x^2 + \{|a_2\beta_3| + |b_2a_3|\}xy + |b_2\beta_3|y^2 = 0 \end{aligned}\right\}$$

we obtain

$$\begin{vmatrix} |a_1a_2| & |a_1\beta_2| + |b_1a_2| & |b_1\beta_2| & . \\ . & |a_1a_2| & |a_1\beta_2| + |b_1a_2| & |b_1\beta_2| \\ |a_2a_3| & |a_2\beta_3| + |b_2a_3| & |b_2\beta_3| & . \\ . & |a_2a_3| & |a_2\beta_3| + |b_2a_3| & |b_2\beta_3| \end{vmatrix} = 0,$$

the left-hand member of which contains the irrelevant factor $|a_2\beta_2|$, being readily shown to be equal to

$$\begin{vmatrix} a_2 & \beta_2 \\ a_2 & b_2 \end{vmatrix} \cdot \begin{vmatrix} |a_1b_2a_3| & |a_1b_2\beta_3| \\ |a_1a_2\beta_3| & |b_1a_2\beta_3| \end{vmatrix}.$$

The object of the present short paper is to draw attention to other modes of procedure, and to formulate the results for n variables.

(2) In the first place, then, it has to be noted that when the number of fractions is the same as the number of unknowns, it is possible to express each of them in terms of the coefficients alone. Thus, having given

$$\frac{a_1x + b_1y + c_1z}{\alpha_1x + \beta_1y + \gamma_1z} = \frac{a_2x + b_2y + c_2z}{\alpha_2x + \beta_2y + \gamma_2z} = \frac{a_3x + b_3y + c_3z}{\alpha_3x + \beta_3y + \gamma_3z},$$

and denoting each of the fractions by $1/r$, we can deduce an equation containing only r and the eighteen coefficients of x, y, z. To this end consider the determinant

$$\begin{vmatrix} a_1 & b_1 & c_1 & a_1 & \beta_1 & \gamma_1 \\ a_2 & b_2 & c_2 & a_2 & \beta_2 & \gamma_2 \\ a_3 & b_3 & c_3 & a_3 & \beta_3 & \gamma_3 \\ \xi_1 & \eta_1 & \zeta_1 & r\xi_1 & r\eta_1 & r\zeta_1 \\ \xi_2 & \eta_2 & \zeta_2 & r\xi_2 & r\eta_2 & r\zeta_2 \\ \xi_3 & \eta_3 & \zeta_3 & r\xi_3 & r\eta_3 & r\zeta_3 \end{vmatrix}, \quad \text{or D say,}$$

where the ξ's, η's, ζ's are any quantities whatever. Performing the operations

$$x \text{ col}_1 + y \text{ col}_2 + z \text{ col}_3, \quad x \text{ col}_4 + y \text{ col}_5 + z \text{ col}_6,$$

we obtain a determinant equal to x^2D whose fourth column is r times its first, and which therefore vanishes. D is thus seen to be equal to 0 for all values of the ξ's, η's, ζ's. But D is clearly equal to

$$\begin{vmatrix} a_1 & b_1 & c_1 & a_1 - ra_1 & \beta_1 - rb_1 & \gamma_1 - rc_1 \\ a_2 & b_2 & c_2 & a_2 - ra_2 & \beta_2 - rb_2 & \gamma_2 - rc_2 \\ a_3 & b_3 & c_3 & a_3 - ra_3 & \beta_3 - rb_3 & \gamma_3 - rc_3 \\ \xi_1 & \eta_1 & \zeta_1 & . & . & . \\ \xi_2 & \eta_2 & \zeta_2 & . & . & . \\ \xi_3 & \eta_3 & \zeta_3 & . & . & . \end{vmatrix},$$

that is

$$-|\xi_1\eta_2\zeta_3| \cdot |a_1 - ra_1 \quad \beta_2 - rb_2 \quad \gamma_3 - rc_3|;$$

hence

$$|a_1 - ra_1 \quad \beta_2 - rb_2 \quad \gamma_3 - rc_3| = 0,$$

—a cubic equation for the determination of r in terms of the original coefficients of x, y, z. The general theorem manifestly is:—*If we have given*

$$\frac{a_1x_1 + b_1x_2 + \ldots + l_1x_n}{a_1x_1 + \beta_1x_2 + \ldots + \lambda_1x_n} = \frac{a_2x_1 + b_2x_2 + \ldots + l_2x_n}{a_2x_1 + \beta_2x_2 + \ldots + \lambda_2x_n} = \ldots\ldots\ldots\ldots = \frac{a_nx_1 + b_nx_2 + \ldots + l_nx_n}{a_nx_1 + \beta_nx_2 + \ldots + \lambda_nx_n} = \frac{1}{r},$$

then

$$|a_1 - ra_1 \quad b_2 - r\beta_2 \quad \ldots \quad l_n - r\lambda_n| = 0. \qquad (I)$$

(3) If the number of equivalent fractions be one more than the number of unknowns,—as, of course, must be the case if elimination is to be expected,—it will be possible to deduce as many results of the type (I) as there are fractions. Thus if $1/r$ in the example just dealt with be also equal to

$$\frac{a_4x + b_4y + c_4z}{a_4x + \beta_4y + \gamma_4z},$$

we have only to leave out in succession the 4th, 1st, 2nd, 3rd fractions, and we obtain

$$\left.\begin{aligned} |a_1 - ra_1 \quad \beta_2 - rb_2 \quad \gamma_3 - rc_3| &= 0 \\ |a_2 - ra_2 \quad \beta_3 - rb_3 \quad \gamma_4 - rc_4| &= 0 \\ |a_3 - ra_3 \quad \beta_4 - rb_4 \quad \gamma_1 - rc_1| &= 0 \\ |a_4 - ra_4 \quad \beta_1 - rb_1 \quad \gamma_2 - rc_2| &= 0 \end{aligned}\right\}$$

or

$$\left.\begin{array}{l} |a_1\beta_2\gamma_3| - \{|a_1\beta_2\gamma_3|+|a_1b_2\gamma_3|+|a_1\beta_2c_3|\}r + \{|a_1b_2c_3|+|a_1\beta_2c_3|+|a_1b_2\gamma_3|\}r^2 - |a_1b_2c_3|r^3 = 0 \\ |a_2\beta_3\gamma_4| - \{|a_2\beta_3\gamma_4|+|a_2b_3\gamma_4|+|a_2\beta_3c_4|\}r + \{|a_2b_3c_4|+|a_2\beta_3c_4|+|a_2b_3\gamma_4|\}r^2 - |a_2b_3c_4|r^3 = 0 \\ |a_3\beta_4\gamma_1| - \{|a_3\beta_4\gamma_1|+|a_3b_4\gamma_1|+|a_3\beta_4c_1|\}r + \{|a_3b_4c_1|+|a_3\beta_4c_1|+|a_3b_4\gamma_1|\}r^2 - |a_3b_4c_1|r^3 = 0 \\ |a_4\beta_1\gamma_2| - \{|a_4\beta_1\gamma_2|+|a_4b_1\gamma_2|+|a_4\beta_1c_2|\}r + \{|a_4b_1c_2|+|a_4\beta_1c_2|+|a_4b_1\gamma_2|\}r^2 - |a_4b_1c_2|r^3 = 0 \end{array}\right\},$$

and thus by eliminating r, r^2, r^3 reach the result

$$\begin{vmatrix} |a_1\beta_2\gamma_3| & \Sigma|a_1\beta_2\gamma_3| & \Sigma|a_1b_2c_3| & |a_1b_2c_3| \\ |a_2\beta_3\gamma_4| & \Sigma|a_2\beta_3\gamma_4| & \Sigma|a_2b_3c_4| & |a_2b_3c_4| \\ |a_3\beta_4\gamma_1| & \Sigma|a_3\beta_4\gamma_1| & \Sigma|a_3b_4c_1| & |a_3b_4c_1| \\ |a_4\beta_1\gamma_2| & \Sigma|a_4\beta_1\gamma_2| & \Sigma|a_4b_1c_2| & |a_4b_1c_2| \end{vmatrix} = 0.$$

The general theorem is :—*The eliminant of the set of equations*

$$\frac{a_1x_1 + b_1x_2 + \ldots + l_1x_n}{a_1x_1 + \beta_1x_2 + \ldots + \lambda_1x_n} = \ldots\ldots = \frac{a_{n+1}x_1 + b_{n+1}x_2 + \ldots + l_{n+1}x_n}{a_{n+1}x_1 + \beta_{n+1}x_2 + \ldots + \lambda_{n\ 1}x_n}$$

is

$$\begin{vmatrix} D_1 & \Sigma D'_1 & \Sigma D''_1 & \ldots. \\ D_2 & \Sigma D'_2 & \Sigma D''_2 & \ldots. \\ \ldots & \ldots & \ldots & \ldots \\ D_{n+1} & \Sigma D'_{n+1} & \Sigma D''_{n+1} & \ldots \end{vmatrix} \qquad \text{(II)}$$

where

$$D_1 \equiv |a_1b_2 \ldots l_n|, \quad D_2 \equiv |a_2b_3 \ldots l_{n+1}|, \quad \ldots, \quad D_{n+1} \equiv |a_{n+1}b_1 \ldots l_{n-1}|$$

and where D'_r *indicates that any one of the letters* D_r *has been replaced by the corresponding letter of the other alphabet,* D''_r *that any two letters have been similarly treated, and so on.*

Of course, since the numerators and denominators of the given fractions may legitimately be interchanged, it would be equally correct to begin in the first column of (II) with α, β, γ, . . . instead of a, b, c, . . . , denoting the elements of the column by Δ_1, Δ_2, . . . , and substituting Δ for D throughout the other columns. By doing so, however, we should only be obtaining the same columns in reverse order, the eliminant being expressible with a superfluity of notation in the form

$$\begin{vmatrix} D_1 & \Sigma D'_1 & \Sigma D''_1 & \ldots. & \Sigma\Delta'_1 & \Delta_1 \\ D_2 & \Sigma D'_2 & \Sigma D''_2 & \ldots. & \Sigma\Delta'_2 & \Delta_2 \\ D_3 & \Sigma D'_3 & \Sigma D''_3 & \ldots. & \Sigma\Delta'_3 & \Delta_3 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ D_{n+1} & \Sigma D'_{n+1} & \Sigma\Delta''_{n+1} & \ldots. & \Sigma D'_{n+1} & \Delta_{n+1} \end{vmatrix}.$$

(4) In connection with the same problem, viz. the elimination of x, y, z when four equivalent fractions are given, let us now consider the determinant

$$\begin{vmatrix} a_1 & b_1 & c_1 & a_1 & \beta_1 & \gamma_1 \\ a_2 & b_2 & c_2 & a_2 & \beta_2 & \gamma_2 \\ a_3 & b_3 & c_3 & a_3 & \beta_3 & \gamma_3 \\ a_4 & b_4 & c_4 & a_4 & \beta_4 & \gamma_4 \\ \xi_1 & \eta_1 & \zeta_1 & r\xi_1 & r\eta_1 & r\zeta_1 \\ \xi_2 & \eta_2 & \zeta_2 & r\xi_2 & r\eta_2 & r\zeta_2 \end{vmatrix}.$$

Proceeding exactly as in § 2 we can show that it must vanish for all values of the ξ's, η's, ζ's: and since it is equal to

$$\begin{vmatrix} a_1 & b_1 & c_1 & a_1 - ra_1 & \beta_1 - rb_1 & \gamma_1 - rc_1 \\ a_2 & b_2 & c_2 & a_2 - ra_2 & \beta_2 - rb_2 & \gamma_2 - rc_2 \\ a_3 & b_3 & c_3 & a_3 - ra_3 & \beta_3 - rb_3 & \gamma_3 - rc_3 \\ a_4 & b_4 & c_4 & a_4 - ra_4 & \beta_4 - rb_4 & \gamma_4 - rc_4 \\ \xi_1 & \eta_1 & \zeta_1 & . & . & . \\ \xi_2 & \eta_2 & \zeta_2 & . & . & . \end{vmatrix},$$

that is,

$$|\eta_1\zeta_2|\cdot|a_1 \quad a_2 - ra_2 \quad \beta_3 - rb_3 \quad \gamma_4 - rc_4| + |\zeta_1\xi_2|\cdot|b_1 \quad a_2 - ra_2 \quad \beta_3 - rb_3 \quad \gamma_4 - rc_4| + |\xi_1\eta_2|\cdot|c_1 \quad a_2 - ra_2 \quad \beta_3 - rb_3 \quad \gamma_4 - rc_4|,$$

or

$$|\eta_1\zeta_2|\cdot|a_1 \quad a_2 \quad \beta_3 - rb_3 \quad \gamma_4 - rc_4| + |\zeta_1\xi_2|\cdot|b_1 \quad a_2 - ra_2 \quad \beta_3 \quad \gamma_4 - rc_4| + |\xi_1\eta_2|\cdot|c_1 \quad a_2 - ra_2 \quad \beta_3 - rb_3 \quad \gamma_4|,$$

it follows that the cofactors here of $|\eta_1\zeta_2|, |\zeta_1\xi_2|, |\xi_1\eta_2|$ must each be equal to zero. This gives us the set of equations—

$$\left.\begin{aligned} |a_1a_2\beta_3\gamma_4| - \{|a_1a_2b_3\gamma_4| + |a_1a_2\beta_3c_4|\}r + |a_1a_2b_3c_4|r^2 = 0 \\ |b_1a_2\beta_3\gamma_4| - \{|b_1a_2\beta_3c_4| + |b_1a_2\beta_3\gamma_4|\}r + |b_1a_2\beta_3c_4|r^2 = 0 \\ |c_1a_2\beta_3\gamma_4| - \{|c_1a_2\beta_3\gamma_4| + |c_1a_2b_3\gamma_4|\}r + |c_1a_2b_3\gamma_4|r^2 = 0 \end{aligned}\right\},$$

from which by elimination of r, r^2 we obtain

$$\begin{vmatrix} |a_1a_2\beta_3\gamma_4| & |a_1a_2b_3\gamma_4| + |a_1a_2\beta_3c_4| & |a_1a_2b_3c_4| \\ |b_1a_2\beta_3\gamma_4| & |b_1a_2\beta_3c_4| + |b_1a_2\beta_3\gamma_4| & |b_1a_2\beta_3c_4| \\ |c_1a_2\beta_3\gamma_4| & |c_1a_2\beta_3\gamma_4| + |c_1a_2b_3\gamma_4| & |c_1a_2b_3\gamma_4| \end{vmatrix} = 0.$$

The general theorem is:—*The eliminant of the set of equations*

$$\begin{aligned} \frac{a_1x_1 + b_1x_2 + \ldots + l_1x_n}{a_1x_1 + \beta_1x_2 + \ldots + \lambda_1x_n} &= \frac{a_2x_1 + b_2x_2 + \ldots + l_2x_n}{a_2x_1 + \beta_2x_2 + \ldots + \lambda_2x_n} \\ &= \ldots\ldots\ldots\ldots \\ &= \frac{a_{n+1}x_1 + b_{n+1}x_2 + \ldots + l_{n+1}x_n}{a_{n+1}x_1 + \beta_{n+1}x_2 + \ldots + \lambda_{n+1}x_n} \end{aligned}$$

is

$$\begin{vmatrix} D_1 & \Sigma D'_1 & \Sigma D''_1 \ldots\ldots \\ D_2 & \Sigma D'_2 & \Sigma D''_2 \ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots \\ D_n & \Sigma D'_n & \Sigma D''_n \ldots\ldots \end{vmatrix} \qquad \text{(III)}$$

where $D_1 = |a_1b_2c_3 \ldots l_na_{n+1}|$, $D_2 = |a_1b_2c_3 \ldots l_n\beta_{n+1}|$, . . . *and where* D'_r *indicates that any one of the italic letters of* D_r *except the* r^{th} *has been replaced by the corresponding Greek letter,* D''_r *that any two letters except the* r^{th} *have been similarly treated, and so on.*

As before, it has to be noted that by changing the D's of (III) into Δ's (viz. $\Delta_1 = |a_1\beta_2 \ldots \lambda_na_{n+1}|$, $\Delta_2 = |a_1\beta_2 \ldots \lambda_nb_{n+1}|$, . . .) we merely reverse the order of the columns.

(5) The eliminant just obtained being different in form from that reached in § 3, we are thus furnished with a very interesting identity in determinants, the establishing of which is well deserving of attention.* (IV)

The simplest case of it is

$$\begin{vmatrix} |a_1b_2| & |a_1b_2| + |a_1\beta_2| & |a_1\beta_2| \\ |a_2b_3| & |a_2b_3| + |a_2\beta_3| & |a_2\beta_3| \\ |a_3b_1| & |a_3b_1| + |a_3\beta_1| & |a_3\beta_1| \end{vmatrix} = - \begin{vmatrix} |a_1b_2a_3| & |a_1\beta_2a_3| \\ |a_1b_2\beta_3| & |a_1\beta_2b_3| \end{vmatrix}.$$

Here the operations

$$a_3 \cdot \text{row}_1 + a_1 \cdot \text{row}_2 + a_2 \cdot \text{row}_3,$$
$$|a_3\beta_1| \cdot \text{row}_2 - |a_2\beta_3| \cdot \text{row}_3,$$

performed on the three-line determinant produce †

$$\begin{vmatrix} |a_1b_2a_3| & |a_1\beta_2a_3| & \cdot \\ a_3|a_1b_2\beta_3| - \beta_3|a_1b_2a_3| & a_3|a_1b_2\beta_3| - \beta_3|a_1\beta_2a_3| & \cdot \\ |a_3b_1| & |a_3b_1| + |a_3\beta_1| & |a_3\beta_1| \end{vmatrix} \div a_3|a_3\beta_1|$$

from which the two-line determinant readily evolves after the performance of the operation

$$\text{row}_2 + \beta_3 \cdot \text{row}_1.$$

(6) In a previous communication to the Society attention has been drawn to the importance, when dealing with elimination in the case of a set of quadrics, of discovering the corresponding set of linear equations. Let us seek, therefore, the set of linear equations in x, y, z which corresponds to the set of quadrics in § 3, viz.

$$\frac{a_1x + b_1y + c_1z}{a_1x + \beta_1y + \gamma_1z} = \frac{a_2x + b_2y + c_2z}{a_2x + \beta_2y + \gamma_2z} = \ldots = \frac{a_4x + b_4y + c_4z}{a_4x + \beta_4y + \gamma_4z}.$$

The mode of reasoning followed in §§ 2, 4 makes clear that on account of the existence of the given equations we have

* This and a cognate identity are formally proved in the *Messenger of Math.*, xxxv. pp. 118–122.

† Note the identity,

$$\begin{vmatrix} |x_2y_3| & |\xi_2\eta_3| \\ |x_3y_1| & |\xi_3\eta_1| \end{vmatrix} = \begin{vmatrix} \xi_3 & \eta_3 \\ |x_1y_2\xi_3| & x_1y_2\eta_3| \end{vmatrix} = - \begin{vmatrix} x_3 & y_3 \\ |\xi_1\eta_2x_3| & |\xi_1\eta_2y_3| \end{vmatrix}.$$

$$\begin{vmatrix} a_1x+b_1y+c_1z & a_1 & \beta_1 & \gamma_1 \\ a_2x+b_2y+c_2z & a_2 & \beta_2 & \gamma_2 \\ a_3x+b_3y+c_3z & a_3 & \beta_3 & \gamma_3 \\ a_4x+b_4y+c_4z & a_4 & \beta_4 & \gamma_4 \end{vmatrix} = 0,$$

$$\begin{vmatrix} a_1 & b_1y+c_1z & a_1x+\beta_1y & \gamma_1 \\ a_2 & b_2y+c_2z & a_2x+\beta_2y & \gamma_2 \\ a_3 & b_3y+c_3z & a_3x+\beta_3y & \gamma_3 \\ a_4 & b_4y+c_4z & a_4x+\beta_4y & \gamma_4 \end{vmatrix} - \begin{vmatrix} a_1x+b_1y & c_1 & a_1 & \beta_1y+\gamma_1z \\ a_2x+b_2y & c_2 & a_2 & \beta_2y+\gamma_2z \\ a_3x+b_3y & c_3 & a_3 & \beta_3y+\gamma_3z \\ a_4x+b_4y & c_4 & a_4 & \beta_4y+\gamma_4z \end{vmatrix} = 0,$$

$$\begin{vmatrix} a_1 & b_1 & c_1 & a_1x+\beta_1y+\gamma_1z \\ a_2 & b_2 & c_2 & a_2x+\beta_2y+\gamma_2z \\ a_3 & b_3 & c_3 & a_3x+\beta_3y+\gamma_3z \\ a_4 & b_4 & c_4 & a_4x+\beta_4y+\gamma_4z \end{vmatrix} = 0.$$

The first and third of these are linear in x, y, z; in the second the two determinants are quadrics, the facients being xy, y^2, zx, yz; but as the coefficient of zx is $|a_1c_2a_3\gamma_4|$ in both determinants, it is possible to remove the factor y, thus making the equation linear also. We consequently have

$$\left.\begin{array}{rcrcrcl} |a_1a_2\beta_3\gamma_4|x & + & |b_1a_2\beta_3\gamma_4|y & + & |c_1a_2\beta_3\gamma_4|z & = 0, \\ \left.\begin{array}{r}|a_1b_2a_3\gamma_4| \\ -|a_1c_2a_3\beta_4|\end{array}\right\}x & + & \left.\begin{array}{r}|a_1b_2\beta_3\gamma_4| \\ -|b_1c_2a_3\beta_4|\end{array}\right\}y & + & \left.\begin{array}{r}|a_1c_2\beta_3\gamma_4 \\ -|b_1c_2a_3\gamma_4|\end{array}\right\}z & = 0, \\ |a_1b_2c_3a_4|x & + & |a_1b_2c_3\beta_4|y & + & |a_1b_2c_3\gamma_4|z & = 0, \end{array}\right\}$$

and thus have solved the problem set ourselves.

In eliminating x, y, z from these, we obtain a result agreeing with that of § 4, and so learn that *the set of linear equations equivalent to the set of quadrics specified in the enunciations of the theorems of §§ 3, 4 has for its coefficients the elements of the conjugate of the eliminant obtained in the latter paragraph.* (V)

The law of formation of the vanishing determinants which originate the said set of linear equations will make its appearance if we take an additional case, say the case where the given equations are

$$\left.\begin{array}{l} a_mx+b_my+c_mz+d_mw \\ a_mx+\beta_my+\gamma_mz+\delta_mw \end{array}\right\} = \frac{1}{r} \qquad (m=1, 2, 3, 4, 5).$$

Here the first linear equation is

$$\begin{vmatrix} a_1x+b_1y+c_1z+d_1w & a_1 & \beta_1 & \gamma_1 & \delta_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+b_5y+c_5z+d_5w & a_5 & \beta_5 & \gamma_5 & \delta_5 \end{vmatrix} = 0,$$

where all the 4 terms of the numerator are kept together, and all the 4 terms of the denominator are separated; the second is

$$\left|\begin{array}{cccc} a_1x+b_1y+c_1z & d_1 & a_1x+\delta_1w & \beta_1 & \gamma_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+b_5y+c_5z & d_5 & a_5x+\delta_5w & \beta_5 & \gamma_5 \end{array}\right|$$

$$-\left|\begin{array}{cccc} a_1x+b_1y+d_1w & c_1 & a_1x+\gamma_1z & \beta_1 & \delta_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+b_5y+d_5w & c_5 & a_5x+\gamma_5z & \beta_5 & \delta_5 \end{array}\right|$$

$$+\left|\begin{array}{cccc} a_1x+c_1z+d_1w & b_1 & a_1x+\beta_1y & \gamma_1 & \delta_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+c_5z+d_5w & b_5 & a_5x+\beta_5y & \gamma_5 & \delta_5 \end{array}\right| = 0,$$

where 3 of the terms of the numerator of which one is always a_mx are kept together, and 2 terms of the denominator of which one is always a_mx, and the other the term corresponding to that rejected from the numerator; the third is

$$\left|\begin{array}{cccc} a_1x+b_1y & c_1 & d_1 & a_1x+\gamma_1z+\delta_1w & \beta_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+b_5y & c_5 & d_5 & a_5x+\gamma_5z+\delta_5w & \beta_5 \end{array}\right|$$

$$-\left|\begin{array}{cccc} a_1x+c_1z & b_1 & d_1 & a_1x+\beta_1y+\delta_1w & \gamma_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+c_5z & b_5 & d_5 & a_5x+\beta_5y+\delta_5w & \gamma_5 \end{array}\right|$$

$$+\left|\begin{array}{cccc} a_1x+d_1w & b_1 & c_1 & a_1x+\beta_1y+\gamma_1w & \delta_1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5x+d_5w & b_5 & c_5 & a_5x+\beta_5y+\gamma_5w & d_5 \end{array}\right| = 0, \quad ($$

where 2 terms of the numerator of which one is a_mx are kept together, and 3 terms of the denominator of which one is a_mx and the two others the terms corresponding to those rejected from the numerator; and the fourth is

$$\left|\begin{array}{ccccc} a_1 & b_1 & c_1 & d_1 & a_1x+\beta_1y+\gamma_1z+\delta_1w \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_5 & b_5 & c_5 & d_5 & a_5x+\beta_5y+\gamma_5z+\delta_5w \end{array}\right| = 0,$$

where the terms of the numerator are all kept separate and those of the denominator are kept all together.

Instead of always including a_mx and a_mx when making our selections, we might take any other corresponding pair; the only difference would be that the factor struck out from the quadric in order to reach the linear equation would not be x, but y or z or w.*

* Had § 2 stood by itself it would of course have been more direct and natural to change its equations into

$$r(a_1x+b_1y+c_1z) = a_1x+\beta_1y+\gamma_1z, \quad \ldots\ldots$$

or

$$0 = (a_1-ra_1)x+(\beta_1-rb_1)y+(\gamma_1-rc_1)z, \quad \ldots\ldots$$

and eliminate x, y, z.

II.—The Varying Form of the Stomach in Man and the Anthropoid Ape.

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There are few organs which have engaged the attention of the topographical anatomist more than the stomach, and few which have yielded him so small a reward as the result of his labours. The changes which so rapidly set in after death through relaxation of its muscular wall, combined with the many different forms which the organ may assume during life, make the investigation one of great difficulty. Improved methods, and more especially the introduction of formalin as a hardening and preserving agent, have, however, placed the modern anatomist in a much more favourable position than his predecessor for attacking problems of this nature, and have enabled him to do justice to many views which have been more or less tentatively put forward by the earlier observers in this branch of study.

The old idea of the stomach as a thin-walled, flaccid, and limp sac may now be said to be a thing of the past. Luschka (30), thirty-two years ago, and more recently Braune (3) have both insisted that the healthy stomach, by contraction of its muscular coat, adapts itself to its contents, whether these be liquid, gaseous, or solid, and when empty and contracted its walls become thick and firm. In this respect, therefore, the stomach behaves in precisely the same manner as other hollow viscera, such as the bladder or intestine. Pfaundler (41), who has recently carried out an elaborate investigation into the capacity of the organ, recognises two distinct types of stomach, which he distinguishes by the terms *diastolic* and *systolic*, and he gives four figures to show the characters presented by each. The diastolic stomach is of large size, with lax walls and uniform curvatures. In short, it reproduces the old conventional picture of the organ. The systolic stomach, on the other hand, which the author states occurs somewhat less frequently, is relatively small, narrow, and irregular in shape, with stiff thick walls. Pfaundler draws an analogy between these phases of the stomach-wall and the diastolic and systolic conditions of the heart-wall

—an analogy which is manifestly erroneous. Indeed, the utility of applying such terms to the stomach is doubtful, seeing that they merely express two extreme conditions of the gastric musculature, between which we find every phase of intermediate gradation.

The varying forms which the stomach may assume under the different conditions to which it is subjected is largely a physiological question. The muscular coat, operated on by a complex nervous mechanism, exercises a dominant influence in determining many of the different shapes presented by the organ, and it is here that improved methods of preservation have proved so helpful in enabling us to catch and retain certain fleeting and temporary phases of stomach contraction which were formerly lost through rapid post-mortem changes.

Much information which has a direct bearing upon the anatomy of the stomach has been recently acquired by the study of its rhythmical contractions as seen through the agency of the Röntgen rays, by the direct examination of the organ in the living animal, and also as the result of clinical research. But the question has likewise its anatomical side. The original form of the stomach in the fœtus, as Hasse and Stricker (17) have pointed out, is largely determined by the character of the chamber in the abdominal cavity it is called upon to occupy, and by the fact that only in the interval between the liver and spleen it is allowed any degree of freedom for its proper expansion. Further, during the later period of intra-uterine life, as shown by Erik Müller (40), and during the whole period of extra-uterine life, the walls of the abdominal recess in which it lies—formed as these are by many parts and organs all more or less subject to individual changes in form, bulk, and position—exercise a potent influence on the shape and position of the stomach.

One of the last papers which Professor His (22) wrote was upon the form and position of the human stomach in subjects hardened by formalin injection. In this communication the condition of the stomach in eighteen individuals is described and illustrated by photographs taken from casts prepared by Herr Steger of Leipzig. For several years I have been engaged in a similar investigation, but in one sense the material at my disposal has not been so plentiful. I have only had three adult males, three adult females, and three children, together with one chimpanzee and two young orangs, specially hardened by formalin injection for this purpose; but then I have had ample opportunity of carrying on my observations on the subjects which have been prepared for ordinary class work, seeing that formalin is now employed in every case to harden the viscera in the abdomen. Indeed, it is from the latter source that some of my most interesting specimens have been obtained. I have also received the most generous assistance in the supply of material from numerous friends. Mr Harold Stiles has placed at my disposal many young specimens, several of which had been carefully hardened *in situ*, together with a number of microscopic sections through the pyloric canal; from Professor Elliot Smith I received a characteristic example of hour-glass stomach; whilst Dr A. Bruce, Dr Shennan, Dr Beattie, Dr Harvey

LITTLEJOHN, Dr GRAHAM BROWN, and Dr D. WATERSTON have in like manner supplied me with valuable material.

It is necessary that I should indicate the methods which were adopted for the purpose of fixing the stomach in its natural form and preserving it in this form after its removal from the body. When the abdominal cavity was opened an incision of about an inch in length was made through the most dependent part of the wall of the organ. By elevating the upper part of the trunk, the fluid contents (when such were present) were thus allowed to flow out. The position of the subject was then changed: the shoulders were depressed and the pelvis raised so as to make the aperture the highest part of the stomach, and by means of a funnel or a syringe (without a nozzle) melted gelatine was allowed to flow gently into the stomach through the incision in the wall. No pressure was employed, and a free overflow of the gelatine was always permitted through the opening which held the funnel or the syringe. Anyone who has knowledge of hollow viscera which have been satisfactorily hardened *in situ* by formalin, will know that the stiffened walls, although they may partially collapse when fluid or gaseous contents are allowed to escape, will recover their original condition when the material withdrawn is replaced by such a substance as gelatine, and further, that so long as force is avoided in introducing the gelatine no distortion will follow. Indeed, when the stomach is in its natural bed, with the other hardened viscera around it and giving it support, the only risk of distortion ensuing from the method described arises from the possibility of the anterior wall of a much-distended organ bulging beyond the curved plane previously occupied by the posterior surface of the anterior abdominal wall. This risk was obviated by allowing the gelatine to trickle in and always permitting a free overflow.

GENERAL FORM OF STOMACH.

Notwithstanding the constantly varying form of the stomach, due to the amount of its contents and the degree of contraction of its muscular coat, the organ presents certain expansions and constrictions which are more or less permanent, although they are frequently much obscured by the physiological changes which it undergoes.

Cardiac Part of the Stomach and Lower End of the Œsophagus.—The expansion or cul-de-sac at the left of the organ, known as the *fundus*, and the notch between it and the lower end of the œsophagus, termed the *incisura cardiaca*, are sufficiently obvious in almost all states of the stomach, and require no special notice. In a recent paper upon the stomach by HASSE and STRICKER (17), the portion of the œsophagus adjoining the stomach is described as consisting of two parts, which are called respectively the ampulla phrenica and the antrum cardiacum.

The ampulla* is a fusiform expansion of the tube of variable length and girth which lies within the thorax immediately above the point where the gullet is grasped between the two muscular margins of the œsophageal opening of the diaphragm.

In several of my specimens it is fairly well marked, and in two, obtained from a young man (Pl. III. fig. 21) and a young male chimpanzee (Pl. I. fig. 7), it is large and conspicuous; but in the majority of cases it cannot be detected.

So far as my experience goes, the ampulla is rarely present in the fœtus (Pl. I. fig. 6). It makes its appearance after the œsophagus becomes functional, and is

* HASSE and STRICKER state that the ampulla phrenica has been previously noticed by MEHNERT. This is a somewhat misleading statement, seeing that MEHNERT (33) does not specially allude to the dilatation; he seeks to show that the œsophagus consists of twelve more or less fusiform enteromeres, and that traces of this metameric subdivision may be seen in the shape of ring-like constrictions in the tube—the typical number of which he believes to be thirteen.

used for the introduction of food or it may be amniotic fluid into the stomach, and the occasional conduction of material out of the stomach. It lies in the lowest part of the posterior mediastinum, where this is bounded in front by the back of the diaphragm, and the occurrence of a dilatation in this situation can readily be explained on mechanical grounds, seeing that at this point the gullet receives less perfect support from its immediate surroundings than elsewhere, and from the fact that it is somewhat compressed immediately above and below the place where the expansion takes place. Above the ampulla the gullet is flattened from before backwards by the application of the pericardium and heart (Pl. I. fig. 10), whilst at the lower end of the dilatation the tube is grasped by the muscular margins of the œsophageal opening in the diaphragm.* An excellent illustration of the ampulla phrenica in relation to its surroundings may be seen in the *Edinburgh Stereoscopic Atlas* (56).

The antrum cardiacum† is merely another name for the intra-abdominal part of the œsophagus. As Hasse and Stricker point out, it is funnel-shaped—the broad end of the funnel being the part by which its junction with the stomach is effected (Pl. I. figs. 6 and 10). This junction takes place at the upper part of the lesser curvature, and it may have the appearance of being to a large extent shifted on to the upper (anterior ?) surface of the stomach in cases where the organ assumes a horizontal position (Pl. I. figs. 7 and 8). As a rule the antrum cardiacum is separated sharply, on its left side, from the fundus by a groove or sulcus termed by His (22) the incisura cardiaca, whereas on its right side it becomes confluent with the lesser curvature, or it may be the upper surface of the stomach, without any bounding demarcation. The incisura cardiaca is seen in the interior of the stomach in the form of a fold or ridge. When the stomach is full and the notch on the exterior is deep, this fold is very projecting, and Braune (3) and His have attributed to it in this condition a valvular action by means of which the gastric contents are prevented from passing back through the cardiac opening into the gullet.

Pyloric Part of Stomach.—The demarcation between the cardiac and pyloric portions of the stomach is seen on the lesser curvature in the shape of a notch or angular depression, which is produced by an elbow-like bend (Cruveilhier (9)) in the organ at this point (Pl. I. figs. 6, 7, and 8). To this notch in the lesser curvature His has applied the term of incisura angularis. Before the peritoneal folds are removed from the stomach the vessels are seen stretching somewhat tightly across the incisura angularis, and when these are taken away and the organ is freed from its omenta, the furrow loses something of its depth and sharpness, unless the abdominal viscera have been hardened *in situ*. The position of the incisura is not always the same; it is influenced by the filling of the stomach; it then tends to move towards the pylorus. In the latter stages of the emptying process it may disappear altogether.

* If an injection mass be forcibly introduced into the stomach, so that there is an escape into the œsophagus, or, on the other hand, if the stomach be forcibly filled through the gullet, an expansion corresponding to the ampulla phrenica very frequently appears on the œsophagus.

† The term antrum cardiacum was first applied by Luschka to this section of the œsophagus.

From the time of the old anatomist WILLIS (59), to whom we owe the doubtful advantage of the introduction of the term 'antrum pylori,' the features presented by the pyloric portion of the stomach have received much attention. CRUVEILHIER (9), ANDERS RETZIUS (44), LUSCHKA (30), JONNESCO (27), ERIK MÜLLER (40), HIS (22), and many others have specially studied this section of the organ, and much confusion has arisen, not only from discrepancies in the descriptions which have resulted, but also from the different names which have been applied to its several parts. The term antrum pylori has been employed in many different senses, and in itself is not a little responsible for much of the obscurity which has gathered around the pyloric part of the stomach. WILLIS applied the name in a somewhat vague way, with the view of distinguishing the part of the organ which adjoins the pylorus. In this country it has been given a more restricted and a more definite application. For the most part British anatomists have indicated by this term the slightly expanded part of the greater curvature which lies opposite the incisura angularis, or, in other words, 'the point' of the elbow-like bend in the stomach as described by CRUVEILHIER. MACALISTER (31), however, uses the term to indicate an expansion on the pyloric part of the lesser curvature. In Germany the term antrum pylori is sometimes applied very much in the original sense of WILLIS, and is understood to include the whole of the pyloric part of the stomach (HENLE (19) and GEGENBAUR (14)); at other times it is restricted to a small section of the stomach, about an inch in length, immediately adjoining the pylorus (LUSCHKA (30)). In France the interpretation of the term has been more in accord with that given to it in this country (JONNESCO and CRUVEILHIER). Considering, then, the striking disagreement amongst anatomists as to the sense in which a term so much in use should be applied, it is not surprising that, in the writings of clinicians and other observers, it is rarely possible to obtain a clear conception of what is meant when we meet with this name. Much credit is due to ERIK MÜLLER for the admirable attempt which he has made to clear away the obscurity which has for so long been a leading characteristic of descriptions of this part of the stomach. The reader who is desirous of making himself more fully acquainted with the historical aspect of the question is referred to the account given by this author. Since MÜLLER's work appeared, HIS has suggested an entirely new terminology for the pyloric region of the stomach. HASSE and STRICKER (17), on the other hand, have retained the offending term antrum pylori, and, following LUSCHKA, have applied it to a section of the stomach for which it is quite unsuited.

Unfortunately, the description given by HIS of the pyloric part of the stomach and the terms which he has suggested in his recent paper are not in every respect satisfactory. The projecting portion of the greater curvature which lies opposite the incisura angularis he calls the camera princeps. Under certain circumstances it may be useful to have a designation for this part of the stomach, and this name, seeing that it is advisable to abolish the term 'antrum,' will do as well as any other. On the right side, the camera princeps is bounded by a faint but very constant furrow in the greater curvature. This

(previously called by Luschka the 'sulcus präpylorica') is placed about an inch or an inch and a quarter from the pyloric constriction (Pl. I. figs. 6, 7, and 8), and to it His has given the name of sulcus intermedius—a term which we may adopt. The short portion of the greater curvature between the sulcus intermedius and the pyloric constriction he designates the camera tertia, and the portion of the lesser curvature from the incisura angularis to the pyloric constriction—comprising, therefore, the entire length of the pyloric part of the lesser curvature—he calls the camera minor. In a considerable number of stomachs, both of man and the chimpanzee, these two latter subdivisions proposed by His are more or less apparent as faint bulgings of the stomach wall (Pl. I. fig. 8); but when the interior of the organ and the structure of its wall are examined, it is seen that the recognition of a camera minor and a camera tertia is unnecessary, and that the terms are inappropriate. There cannot be a doubt that Jonnesco (27) and Müller (40) have attained the proper conception of this portion of the stomach by subdividing it into two parts, to which the former author has applied the terms of pyloric canal and pyloric vestibule.

Pyloric Canal.

Although the pyloric canal is by no means constant in form, and undergoes striking changes in accordance with altered physiological conditions of the stomach, there is no part of the organ which is more definite and distinct. It is, as a rule, a short, more or less tubular portion about an inch or so in length (3 cm., Jonnesco), which extends from the sulcus intermedius in the greater curvature to the duodeno-pyloric constriction (Pl. I. figs. 6, 7, and 8). Its demarcation from the pyloric vestibule is rendered the more evident by the fact that usually, on the other side of the sulcus intermedius, the greater curvature bulges out into a marked expansion (camera princeps of His); but on the side of the lesser curvature it is not usual to find in the adult any limiting mark on the exterior separating the pyloric canal from the rest of the stomach. Jonnesco, it is true, describes at this point a sulcus ('le sillon pylorique supérieur') which, he states, indents the lesser curvature between the pyloric canal and the pyloric vestibule. This is a rare occurrence in the adult, although it is not uncommon in the fœtus and child. In the latter the appearance is not so much due to a constriction as to a widely expanded pyloric vestibule giving place suddenly to a tightly contracted pyloric canal (see the figures in Pl. X. accompanying Erik Müller's memoir (40)). In figs. 6, 7, and 8, Pl. I., the external characters presented by the pyloric canal in the fœtus, the chimpanzee, and a child of two years are well seen.

By making a section through the pyloric part of the stomach in the plane of the two curvatures, the characters presented by its two parts can be more fully appreciated. This has been done in the case of the stomach of the child and of the chimpanzee referred to above, and the appearances presented by each are figured in Pl. II. figs. 15 and 16. In both, the pyloric canal is contracted along its whole length, and in the case of the

child's stomach (fig. 16) the lumen is obliterated by closely packed longitudinal folds of mucous membrane. The communication between the canal and the vestibule is placed close to the lesser curvature, whilst opposite to this the vestibular part of the greater curvature forms an expanded bay or pocket. But ERIK MÜLLER has given such an admirable account of the pyloric canal in the fœtus and child that it is not necessary to say more on this subject, beyond emphasising the fact that it is in these early stages that the best conception of this part of the stomach as a distinct section of the organ can be obtained.

In the adult it is much more common to find the canal partially or completely expanded, and in this condition its demarcation from the pyloric vestibule becomes less pronounced. Its tubular character, however, is rarely entirely lost, and when a section is made through the stomach in the plane of the curvatures, the appearance presented by the interior makes the subdivision between these two parts of the stomach sufficiently clear. Every phase, from the most complete contraction, with obliteration of the cavity, to the fullest degree of expansion of the pyloric canal, is met with; but in very few cases, and these, as a rule, not normal specimens, do we see the pyloric canal so expanded that its cavity merges into that of the pyloric vestibule without any indication of subdivision in the interior of the organ.

The problem as to what are the conditions which produce, on the one hand, a firmly contracted, cylindrical canal, with an obliterated lumen, and, on the other hand, a partially relaxed or completely patent and capacious pyloric canal, is one of great difficulty. An identical contraction-phase of the canal is not infrequently associated with absolutely different contraction-phases of the rest of the stomach. Thus, in cases where the stomach is contracted and empty, it does not follow that the pyloric canal is contracted likewise. Indeed, in such conditions of the stomach, it has been my experience to find the canal as a rule partially expanded. Again, in the widely expanded stomach all phases in the condition of the pyloric canal are met with—from one tightly contracted in its whole length to one which is partially relaxed or completely dilated. Still, I think it may be assumed that the contracted canal is more frequently found associated with the full than with the empty stomach.

From the circumstances stated above, we may reasonably infer that the musculature of the pyloric canal in all probability acts to some extent independently of that of the rest of the stomach, and is under the control of a special nervous mechanism.

The extremity of the pyloric canal protrudes into the commencement of the duodenum (Pl. II. figs. 15 and 16), so that, when viewed from the duodenal side, it presents the appearance of a smooth, rounded knob with a small puckered aperture, the pyloric opening, in its centre, and surrounded by a shallow groove or fornix. The resemblance which it presents, as I pointed out many years ago, to the portio vaginalis of the cervix uteri is very striking. In the full-time fœtus the protrusion of the termination of the pyloric canal into the duodenum is more marked than in the adult,

and almost suggests a slight degree of telescoping of the one into the other.* In the cadaver which has been properly prepared by formalin injection, the pyloric opening is almost invariably found tightly closed—no matter what the condition of the pyloric canal may be. It is only on very rare occasions that the opening is patent. In such cases it is circular, surrounded by the ring-like ledge which has been called the pyloric valve, and may be large enough to admit the point of the little finger; but this is not a natural condition. It is safe to conclude that during life the pyloric opening at the extremity of the pyloric canal is always rigidly closed, except during digestion, when it opens intermittently and at irregular intervals (Hirsch (20) and Cannon (6)) to allow the passage of material from the stomach to the duodenum.†

The musculature of the pyloric canal constitutes, as Müller (40) has pointed out, one of the leading peculiarities of this section of the stomach. Both the longitudinal and the circular fasciculi are present in greater mass than in any other part of the organ. The circular fibres are disposed in the form of a thick sphincteric muscular cylinder which surrounds the entire length of the canal (Pl. II. figs. 15 and 17; see also Pl. IV. fig. 40). At the duodeno-pyloric constriction the margin of this cylinder becomes increased in thickness, forming thereby the massive muscular ring which encircles the pyloric opening and constitutes the pyloric sphincteric ring. The knob-like appearance presented by the extremity of the pyloric canal when viewed from the interior of the duodenum is produced by the presence, beneath the mucosa, of this muscular ring. The sphincteric cylinder which surrounds the pyloric canal varies much in its thickness in accordance with different degrees of contraction of the canal. In the firmly contracted condition, and when in consequence the canal is tightly closed, the muscle-layer is very nearly equally thick throughout its whole length. This is more especially the case on the side of the greater curvature where the circular muscular fibres turn over the sulcus intermedius before they finally thin down (Pl. II. figs. 15 and 16) and gradually become uniform in thickness with the circular fibres of the pyloric vestibule. On the lesser curvature side of the canal the transition is, as a rule, less abrupt, and a gradual diminution in thickness takes place as this layer is traced from the sphincteric ring towards the pyloric vestibule. It would appear, therefore, that the sphincteric cylinder on this side is rather weaker (or perhaps less firmly contracted) than on the greater curvature side—a circumstance which may be due to the close apposition of this aspect of the pyloric canal with the liver.

The longitudinal muscle-fibres likewise form a thick layer on the superficial aspect of the sphincteric cylinder and ring. They are uniformly disposed around the pyloric canal, but as a rule comparatively few of these fibres pass superficially over the duodeno-

* The projection of the extremity of the pyloric canal into the commencement of the duodenum has been stated by various observers to be one of the signs of pyloric stenosis in the infant (Pflaundler, p. 75 (41)). In all probability the condition is more pronounced in these cases.

† The passage of bile into the stomach shows that under certain conditions incontinence of the pyloric opening may take place. As might be expected, bile flows more readily into the empty than into the full stomach (Kussmaul, p. 1651 (29)).

pyloric constriction and become continuous with the corresponding fibres of the duodenum. As they approach the duodenum the deeper longitudinal fibres leave the surface and, in the form of distinct fasciculi, penetrate the substance of the pyloric sphincteric ring, amidst the bundles of which they end—many, however, reaching its deep aspect (Pl. II. figs. 15 and 16). It is not necessary to submit sections of the pyloric canal to microscopic examination to see these fasciculi. They can be observed by the naked eye, or at least with the aid of a magnifying glass, in most sections through this region, and in no specimens in my possession are they so strongly marked as in the stomach of the chimpanzee (fig. 15). This does not seem to be due to a greater development of these fibres in this animal, but to the coarser character of the penetrating fasciculi.

There can be no question that by this arrangement of the pyloric longitudinal fibres in relation to the underlying circular fibres an effective apparatus, antagonistic to the sphincteric ring, is provided, by means of which, when the sphincter relaxes, the pyloric orifice may be dilated. Luschka, who was apparently not aware of the penetration of the sphincteric ring by the longitudinal fibres, was nevertheless of the opinion that the longitudinal fibres were dilators of the pylorus—a view which is endorsed by the physiologist. In the article on 'Digestion' in Schäfer's *Text-book of Physiology*, Starling (49) remarks: "A partial relaxation of this opening (pyloric opening) is brought about, partly by inhibition of the circular sphincter pylori, partly by contraction of the longitudinal fibres."

Rüdinger has given an account of the arrangement of the muscular fibres of the pylorus ("Ueber die Muskelanordnung im Pförtner des Magens und Anus," *Allg. Wien. Med. Ztg.*, 1879, xxiv. 2. 9), but I regret to say that I have not been able to obtain his paper. Jonnesco (27 ; p. 223), who refers to Rüdinger in his description of the structure of the pylorus, remarks: "In effect the longitudinal fibres take part in the formation of the pyloric sphincter by interlacing with the circular fibres: there is thus a constrictor and a dilator of the pylorus."

The description which is given by Luschka (30) (1863) and Brinton (4) (1864) of the longitudinal fibres of the stomach is not generally adopted by British anatomists, and yet anyone who looks into the matter can have little difficulty in satisfying himself as to its general accuracy. According to these authors, the longitudinal fibres of the œsophagus radiate over the stomach in all directions, but more particularly along the lesser curvature, and they disappear (with the exception, perhaps, of some on the lesser curvature) before they reach the pyloric part of the organ. On the body of the stomach a new and independent set of longitudinal muscle-fibres take origin, and these form a layer which gradually gains strength as it sweeps onwards towards the pylorus. These are the fibres which for the most part come to an end by dipping in to mix with the circular fasciculi of the sphincteric pyloric ring.

When longitudinal sections through the pyloric canal, in the plane of the two curvatures of the stomach, are prepared for microscopical examination, the sphincteric cylinder and ring are seen to be broken up into fasciculi of different sizes by strands of connective tissue which enter the muscular tissue on its deep aspect from the sub-

mucosa. These connective tissue septa present different appearances in specimens which show different degrees of contraction of the muscular fasciculi. When the sphincteric girdle is tightly contracted the spaces between the fasciculi become reduced, and the septa are compressed and slender; when, on the other hand, the muscle is relaxed the spaces open out and the contained connective tissue is not so condensed. It is necessary to mention this apparently simple and obvious matter, seeing that its significance has not been fully appreciated by certain observers who have given descriptions of pathological conditions of the pyloric canal.

At the duodeno-pyloric junction, where the musculature of the stomach gives place to the musculature of the intestine, several points of interest may be noted. The connection between these two portions of the alimentary canal is not of so simple a character as it is usually represented to be, and there is much variability in the arrangement of both circular and longitudinal muscular fibres in different specimens. It becomes necessary, therefore, that each specimen should be studied separately.

Pyloric Canal of a Full-time Fœtus (Pl. II. fig. 17; preparation by Mr Stiles).—The layer of circular muscular fibres which forms that part of the sphincteric cylinder which corresponds to the greater curvature is distinctly thicker than that on the opposite side. It rapidly and uniformly increases in thickness until the duodeno-pyloric junction is reached, and here it comes to an end in such a manner that the pyloric sphincteric ring on this side presents a broad, flat margin towards the duodenum. On the other side (*i.e.* lesser curvature side) the margin presented by the pyloric sphincteric ring towards the duodenum is rounded, and as the muscular layer is traced from this to the left over the pyloric canal it is seen to rapidly diminish in thickness. There is no sudden or abrupt transition from the sphincteric cylinder to the sphincteric ring. The pyloric canal is not fully contracted in this specimen.

On both sides the circular muscular coat of the duodenum is absolutely cut off from the fasciculi of the sphincteric ring by a distinct connective tissue septum. There is thus no direct continuity between the circular muscular coat of the stomach and the corresponding coat of the duodenum. On the greater curvature side of the section the circular fibres of the duodenum begin on the duodenal face of the sphincteric ring in the form of three rounded or oval bundles, which are quite separate and which are quickly succeeded by the closely applied fasciculi of the circular coat of the duodenum. On the opposite side (lesser curvature side) the duodenal circular coat has an independent wedge-shaped commencement opposite the duodeno-pyloric constriction.

On both sides of the section a few of the superficial longitudinal fibres of the pylorus are carried over the duodeno-pyloric constriction and become continuous with the longitudinal coat of the duodenum. These fibres, more especially on the greater curvature side, form a very small part of this layer. A large proportion of the deeper fibres, as they approach the pyloric opening, dip into the subjacent sphincteric cylinder and traverse the substance of the sphincteric ring in the form of conspicuous diverging strands, many of which reach the submucosa. The intermediate longitudinal fibres also dip into the sphincteric cylinder, but they keep near to the surface, and run parallel to it, forming here an intimate intermixture of longitudinal and circular fibres. A tolerably thick layer of this muscular feltwork is prolonged over the duodeno-pyloric junction, so as to overlap the commencement of the duodenum on the superficial aspect of its proper circular coat. It finally comes to an end a few millimetres beyond the pylorus by gradually passing into the proper longitudinal coat of the duodenum.

In this specimen, therefore, it will be seen: (1) that there is no continuity between the proper circular coat of the duodenum and the circular coat of the pylorus; (2) that the circular fibres which are carried from the pylorus lie superficial to the circular coat of the duodenum, and on the same plane as the longitudinal fibres of the duodenum, to which they gradually give place.

Pyloric Canal of a Child (preparation by Mr Stiles).—The arrangement of the muscular tissue in this specimen is very similar to that in the preceding section; indeed, on the lesser curvature side of the pyloric

canal and duodenum it is in every respect identical. On the greater curvature side, however, there are some points of difference. The sphincteric ring of the pylorus and the circular muscular layer of the duodenum are arranged in precisely the same way. The difference consists in the manner in which the pyloric longitudinal and circular fibres are prolonged on to the duodenum. At the duodeno-pyloric constriction they form a feltwork, but beyond this the circular fibres free themselves from the longitudinal fibres and are continued for a short distance on the duodenum as a distinct layer on the superficial aspect of the longitudinal fibres. It thus happens that on this side the first part of the wall of the duodenum exhibits three muscular layers, viz., from without inwards—

(*a*) circular
(*b*) longitudinal } prolonged from pylorus.
(*c*) circular — the proper duodenal coat.

Very soon the superficial circular fibres disappear and the longitudinal fibres come to the surface.

Pyloric Canal of a Child (preparation by Mr Stiles).—In this specimen only the greater curvature side of the pyloric canal and the adjoining portion of the duodenum are shown. The proper circular coat of the duodenum does not begin at the sphincteric ring, but at some little distance from it, so that there is a complete break between the circular coats of the stomach and the intestine. Further, no superficial longitudinal fibres are carried from pylorus to duodenum. A thick layer of circular fasciculi continuous with the superficial part of the sphincteric ring is carried on to the duodenal wall, and this constitutes the only muscular covering for a short piece of the initial part of the duodenum. After it has proceeded for a short distance, it is gradually replaced by the proper longitudinal coat of the duodenum.

Pyloric Canal of a Child (Pl. II. fig. 18).—In this specimen the arrangement of the muscular fibres is more simple. On both sides a certain proportion of the more superficial of the longitudinal fibres are carried continuously from the pylorus on to the duodenum, but the layer which they form is much thicker on the greater curvature side, and here they are very wavy. The circular muscular coat of the duodenum is quite distinct from the sphincteric ring of the pylorus. On the lesser curvature side it is separated from it by an interval of a few millimetres; on the opposite side the circular fasciculi of the duodenum begin close to the sphincteric ring, but are separated from it by a very evident partition of connective tissue. At the pyloric constriction certain of the longitudinal fibres and the superficial circular fibres become interwoven together, and with these there is a considerable admixture of connective tissue.

A study, therefore, of these specimens (the majority of which, it will be seen, were prepared by my colleague, Mr H. Stiles) brings out the following points:—

1. The greater proportion of the pyloric longitudinal muscular fibres do not pass on to the duodenum. They turn into the sphincteric ring and there spread out in the form of diverging fasciculi, many of which reach the subjacent submucosa.

2. In only one specimen did the whole of the longitudinal fibres of the pylorus pass into the sphincteric ring; and in this case the superficial circular fasciculi of the pyloric sphincteric ring were carried beyond the duodeno-pyloric constriction so as to form, for a short distance on the duodenum, a layer which gradually gave place to its proper longitudinal coat.

3. In all the other sections the more superficial of the pyloric longitudinal fibres are continued from the stomach on to the duodenum, but the manner in which they are disposed in the region of the duodeno-pyloric junction differs in different individuals.

4. The more usual way is for certain of the pyloric longitudinal fibres to proceed uninterruptedly from stomach to intestine, whilst the more deeply placed fibres form an interlacement with the superficial circular fibres of the sphincteric ring, and the feltwork which results is then carried as a distinct layer for a short distance on to the duodenum.

This lies superficial to the proper circular coat of the duodenum, and very soon gives place to the proper longitudinal coat of the intestine.

5. In other cases all the pyloric longitudinal fibres, which do not dip into the sphincteric ring to end there, pass on to the duodenum without any admixture of the circular fibres of the stomach.

6. The proper circular coat of the stomach is not continuous with the proper circular coat of the duodenum, and is sometimes separated from it by a considerable interval.

7. When circular fibres are continued from the stomach to the intestine they are prolonged from the superficial part of the sphincteric ring, and are mixed with the longitudinal fibres to form the feltwork already referred to.

8. The arrangement of the component parts of the musculature of the pyloric canal suggests that the longitudinal fibres by their contraction will tend not only to open the pyloric aperture when the sphincteric ring is relaxed, but that they will likewise tend to protrude the pylorus more fully into the duodenum and exert a pull on the initial part of the duodenal wall, so as to drag it to some extent over the thickened end of the pyloric canal. Such an action would clearly be advantageous to the proper passage of material into the duodenum.

Up to the present the physiologist has not recognised the pyloric canal as a special portion of the stomach, and we have therefore no information as to the part which it plays in the motor mechanism of the organ. That it has an important action cannot be doubted: its powerful musculature bespeaks the fact. The question which naturally suggests itself is, whether the entire length of the sphincteric cylinder is to be reckoned with the expelling or with the retaining forces of the stomach, or whether it is to be regarded as acting in both ways, and the sphincteric ring as being alone endowed with a continuous sphincteric function. Clinical evidence would seem to point to the entire muscular cylinder being under certain circumstances employed as a sphincter, and thereby closing the whole length of the pyloric canal against the entrance of material from the stomach. In those cases of pyloric stenosis in the infant which, of late years, have attracted so much attention, it is not the sphincteric ring alone that is at fault and prevents the passage of the gastric contents into the duodenum. The circular musculature of the entire length of the pyloric canal, by its spasmodic contraction, leads to the closure of this section of the stomach. On the other hand, we have noted that in the adult it is more usual to find the sphincteric cylinder relaxed and the ring alone contracted: and in this connection it is not without significance that if anything it is more common to find the entire pyloric canal contracted and closed in the full than in the empty stomach.

But in considering this matter the outline drawings of Cannon (6), which show the condition of the stomach during digestion, are of much importance. If reliance is to be placed upon these in deciding a question of detail such as this, it would appear that the pyloric canal in the cat is fully opened upon the arrival of the successive constriction waves which pursue each other over the pyloric part of the stomach while the digestive

process is in progress. At the same time it should be borne in mind that, even granting that this takes place in the cat, it does not necessarily follow that a similar event occurs in the primate. The pyloric canal of the cat, in so far as its musculature is concerned, is not so distinctly specialised, nor is this section of the stomach so obviously a separate part of the organ as in man and the anthropoid ape.

The pyloric region of the cat in several specimens has been examined, and sections were prepared for microscopic study in the same manner as in the case of the human stomach (Pl. II. fig. 20).

The pyloric canal of the cat is relatively longer than in the primate; but although it forms an obviously distinct part of the stomach, its demarcation from the pyloric vestibule is not so definite, seeing that, in both the full and empty states of the organ, the entire length of the pyloric portion is more or less tubular, and the pyloric vestibule does not present the appearance which is characteristic of man and the anthropoid.

The duodeno-pyloric constriction is very pronounced on the greater curvature side, where it forms a deep indentation. On the opposite aspect there is little indication on the surface where the stomach ends and the intestine begins.

The musculature of the pyloric canal also differs in some particulars from that in man. It is more massively developed on that aspect of the canal which corresponds to the greater curvature than on the opposite aspect. On this side likewise the sphincteric ring attains a great thickness, and stands out very prominently. On the lesser curvature side a special thickening of the circular musculature at the duodeno-pyloric junction does not exist even in the contracted state of the muscle; at least, in none of the specimens which I have specially prepared does such a thickening exist in this situation. On the lesser curvature side, therefore, except when the musculature of the pyloric canal is contracted (as in fig. 20), the circular coat is not sharply marked off from that of the intestine or of the pyloric vestibule.

Again, the longitudinal fibres of the pyloric canal do not present the same intimate relation to the sphincteric ring as in man. On the lesser curvature side they are very poorly developed and do not enter the circular coat; and even on the opposite side, where the ring is strongly pronounced, I have not been able to trace any of them into it.

Upon the whole, I am inclined to believe that the sphincteric cylinder in its whole length exercises a double function, and acts both as a retaining and as an expelling agent. Hirsch (20), in a short but very important paper, gives a graphic account of the force with which material is ejected from the stomach into the duodenum;* and Cannon (6) describes the manner in which he saw it 'spurted' from the one into the other. The high pressure which is employed in propelling a portion of the gastric contents into the intestine can be easily understood when we remark the power of the musculature which surrounds the wall of the pyloric canal. But, having made this effort, there is some reason for the belief (until more conclusive evidence on the other side is forthcoming) that during digestion the sphincteric muscular cylinder in its whole length remains contracted until the time for the expulsion of another portion of the gastric contents comes round.

While engaged in the consideration of the various problems suggested by the structure of this part of the stomach, my colleague, Mr Harold Stiles, directed my attention to the important lesson which may be learned regarding the function of the pyloric canal from cases of so-called pyloric stenosis in infants; and through his generous

* Hirsch describes it thus: "Die Intervalle waren in den ersten Stunden kürzer und die ausströmenden Massen verliessen die Kanule unter stärkerem Druck (im Bogen), in den späteren Stunden wurden die Intervalle etwas länger und das Ausströmen fand unter Schwächerem Druck statt."

kindness I have been enabled to study a considerable number of stomachs which present this pathological condition. He has likewise placed in my hands several microscopic sections through the stenosed pyloric region of the infant. In addition to these, I have had a number of other sections prepared by my assistant, Mr JOHN HENDERSON.

In pyloric stenosis the free and regular outflow of the gastric contents is prevented by an abnormal condition of the pyloric canal. In this disorder the whole length of the canal is involved, and any changes which may be apparent in the musculature of the other parts of the stomach are merely secondary and compensatory to those in the pyloric canal.

The pyloric canal in such cases presents the appearance and has the feel of a hard, solid cylinder, about $\frac{7}{8}$ths of an inch in length. It is sharply marked off at its two extremities from the duodenum on the one hand and the pyloric vestibule on the other. In many instances the girth of the canal is not the same throughout its whole length; in the more extreme cases the canal narrows towards its two ends, and thus assumes an oval or fusiform shape somewhat like that of an olive.

All those who have made a microscopic examination of the pyloric canal in this condition are agreed that there is an excessive development of the muscular coat, although, from the different accounts which are given, it would appear that the relative extent to which each of the two muscular layers is involved in this hypertrophy is not the same in every case. A few examples selected from the voluminous literature of the subject will best illustrate this point. HIRSCHSPRUNG (21) states that relatively the longitudinal fibres are the more strongly developed; FINKELSTEIN (13) gives an account of a case in which the same layer was so strongly developed that it was chiefly responsible for the muscular thickening; in GRAN'S (16) case the hypertrophy was confined to the circular fibres; in SCHWYZER'S (48) case the longitudinal fibres were slightly increased, whilst the circular layer was greatly hypertrophied. These observations are sufficient to show that the musculature of the stenosed pyloric canal does not in every case present the same features. At the same time, a glance through the literature makes it evident that the usual condition in such cases is one in which both layers are hypertrophied.

The specimens submitted to me by Mr STILES, as well as those prepared in this department, show a great thickening of both the muscular layers. I would not venture, however, to hazard a decided opinion as to whether they are both hypertrophied to relatively an equal extent, or whether, as most observers believe, the circular sphincteric cylinder has undergone the greater degree of thickening. Measurements do not give reliable information on this point, because a large amount of the thickening is due to contraction, and there are no means by which the degree of contraction in each layer can be estimated. Speaking broadly, the thickness of the circular layer is from three to four times as great as that of the longitudinal layer in the different specimens examined. This would seem to indicate a relatively greater degree of hypertrophy in the longitudinal layer, which, indeed, I believe to be the case.

When sections through the stenosed pyloric canal are examined under the microscope, the general arrangement of the muscular fasciculi—both circular and longitudinal—is seen to have undergone little or no alteration. The great strands of longitudinal fibres which enter the sphincteric ring are particularly conspicuous, whilst the feltwork of mixed longitudinal and superficial circular fibres forms a thick layer at the duodeno-pyloric constriction which is carried on to the initial part of the duodenum. It should be noted that it is usual to find the muscular coat of the duodenum close to the pylorus (for a distance of from 6 to 8 mm.) much hypertrophied (Pl. II. fig. 19).

Three of the leading views advanced as to the nature of the stenosis and the interference with the free outflow of gastric contents may now be briefly alluded to. PFAUNDLER (41) holds that there is no muscular hypertrophy in the wall of the pyloric canal, and that the appearances which seem to indicate this, as well as the results which ensue, are all due to a spasmodic contraction of the circular musculature of this portion of the stomach. The stenosis, therefore, according to this author, is not caused by a structural change, but is produced by a functional disturbance of the nervous mechanism which presides over the movements of the stomach.

Others are of the opinion that the primary and real cause of the stenosis is a true congenital hypertrophy of the muscle in the region involved. Dr JUSSUF IBRAHIM (26) is an able exponent of this theory.

Dr JOHN THOMSON (53, 54, 55) has enunciated a more elaborate hypothesis. He points out the difficulty involved in conceiving a hyperplasia of muscle-fibres except under the influence of increased functional activity. He therefore considers that spasm of the muscular coat of the pyloric canal is the initial and primary mischief, and that this takes place in the fœtus *in utero* through some defect in the nervous mechanism which co-ordinates the expelling and retaining forces of the stomach wall. It is well to note that in the stenosed pylorus the retaining forces are represented by the entire length of the sphincteric muscular cylinder of the pyloric canal. The hypertrophy of the musculature, according to THOMSON, is secondary, and is due to its excessive activity as indicated by its state of spasmodic contraction.

This is not the place to take part in a controversy in which so many matters completely outside the main object of this investigation are involved. Still, there are some points mixed up with the question which specially bear on the structure and function of the pyloric canal, and in so far as these are concerned it may be admissible to pursue the subject.

I must admit that in the first instance I was much biassed in favour of PFAUNDLER'S contention, that the stenosis was merely due to a spasm of the sphincteric cylinder of the pyloric canal, and that the appearance of hypertrophy was entirely due to the strong degree of contraction of the muscle-fibres. Sections which I had made through other contracted portions of the stomach wall had shown me how greatly thickened the circular coat may become when strongly contracted. When I came, however, to study the sections through the stenosed pyloric canal and compare these with normal

specimens, I was soon convinced that here we had a real hypertrophy, and that even an excessive or spasmodic contraction of the muscle-fibres could not give rise to the enormous thickening of the musculature seen in these cases.

It is evident that IBRAHIM (26) appreciates the force of THOMSON's argument, that to obtain a muscle-hypertrophy it is necessary to assume an antecedent muscle-activity, because he puts forward a morphological suggestion to account for the hypertrophy in the stenosed pyloric canal being the antecedent and primary condition.

From an examination of three children which had been born prematurely in the seventh or eighth month, and which had lived several weeks, IBRAHIM has gained the impression that the pylorus presents at this period a relatively greater size, and possesses a relatively greater amount of muscular tissue, than at later stages of development. He consequently suggests that the stomach passes through a developmental phase similar to the condition present in the infantile uterus, in which the fundus is small, and the cervix of inordinate size. Having reached this conclusion, the step which leads to the hypothesis which he puts forward is comparatively simple. He considers that the stenosed pylorus of the infant is to be regarded merely as the retention of a transitory developmental condition present in the stomach from the seventh to the eighth month of intra-uterine life.

Unfortunately, the force of this somewhat far-fetched argument is weakened by the fact that it rests upon an altogether fallacious basis. There is absolutely no ground for the statement that the musculature of the pyloric canal in the fœtus at this stage in its development is relatively more strongly developed than in the later stages. So far from this being the case, it is evident from sections in my possession that at this period of development it is more weakly expressed than in the full-time fœtus.

None of the views on the many complex questions involved in pyloric stenosis in the infant can be considered as being altogether satisfactory; but it appears to me that THOMSON's hypothesis, in the present state of our knowledge, best meets the circumstances of the case. It is true that IBRAHIM puts forward several more or less cogent arguments against it, and he points to FINKELSTEIN's case, in which there was excessive development of the longitudinal muscle-fibres of the pyloric canal, as being unfavourable to this view.* So far from this being the case, the hypertrophy of this layer, which was present in a marked degree in all the specimens I have had the opportunity of examining, may be looked upon as the natural accompaniment of a prolonged spasm of the sphincteric cylinder and ring. As we have noted, there is good reason to believe that these longitudinal fibres have an important part to play in dilating the pyloric opening. Spasmodic contraction of the sphincteric apparatus would necessarily lead to excessive exertion on the part of the antagonistic longitudinal fibres, and thereby lead to an increased development of this layer. The fusiform shape which the pyloric

* It may be as well to say that FINKELSTEIN's (13) statement on this matter and the diagram which he gives are not satisfactory, and raise doubts as to whether he has correctly differentiated between the two muscle-layers in the wall of the pyloric canal.

canal assumes in these cases is no doubt the product of the strong pull which these fibres exert on the duodenal extremity of the pyloric canal.

Pyloric Vestibule (Pl. II. figs. 15 and 16).

This subdivision of the pyloric part of the stomach intervenes between the incisura angularis and the pyloric canal. It is usually pouched out on the side of the greater curvature so as to form the 'coude de l'estomac,' of Cruveilhier or the camera princeps of His. Erik Müller (40) has shown that the pyloric vestibule is much larger in the child than in the fœtus. It is interesting to note that in the chimpanzee the pyloric vestibule is of small size, and in this respect resembles the stomach of the human fœtus.

Influence of Peristaltic Movements upon the Shape of the Stomach.

Under this heading it is my desire to bring the anatomy of the stomach more fully into line with the important results which have been recently obtained by investigation into the movements of the organ during the progress of digestion. In some measure it has been rendered possible to do this by the improved methods, now at our disposal, of fixing in a permanent way certain phases of stomach activity which, through their fleeting character and through rapid post-mortem change, have hitherto to a large extent escaped attention. In the numerous discussions which have taken place upon bilocular or hour-glass stomach, frequent reference is made to functional contraction of the gastric wall, and many valuable observations on this matter have been recorded; but with this exception the anatomist has not given serious attention to the marked changes which occur in the form of the organ as the result of the peristaltic movements of its wall. These have been considered to lie more within the province of the physiologist, and consequently, whilst the anatomy of the passive organ has been studied with elaborate care, the anatomy of the active stomach has received little thought. This is a very limited and circumscribed view to take of a subject so important and so full of interest. The periods of digestive activity, as we know from the labours of the physiologist,* are often very prolonged (see on this point the observations of Hirsch (20)), and the stomach-forms presented at such times are as characteristic and distinctive as those which are exhibited by the organ when in a state of rest.

The stomach represented in Pl. III. fig. 23, obtained from an adult male, may be taken as the type of a form which is not infrequently seen in cases where the subject has been carefully preserved shortly after death. The organ is divided into two well-defined portions by a deep constriction or infolding of the wall which cuts into the

* "In a cat that finished eating 15 grammes of bread at 10.52 a.m., the waves (*i.e.* peristaltic waves of the stomach) were running regularly at 11.00 o'clock. The stomach was not free from food till 6.12 p.m." (Cannon (6).)

greater curvature about the middle of the 'body'* of the stomach. It should be noted that no corresponding constriction occurs on the lesser curvature. The two parts of the stomach which are thus mapped off from each other present a marked contrast. The portion to the left of the constriction constitutes a more or less globular sac with relatively thin walls; the part to the right has assumed the form of a long tube, intestiniform in appearance, with thick, firmly contracted walls. These sharply defined subdivisions may be distinguished by the terms cardiac sac and gastric tube.

The cardiac sac, immediately below the cardiac opening, has a girth of 255 mm., and along the greater curvature, from the entrance of the œsophagus to the constriction, it measures 235 mm. The gastric tube, on the other hand, at its junction with the cardiac sac, has a girth of 88 mm., and at the incisura angularis a girth of 125 mm. The length of the tube, measured along the greater curvature, is 215 mm. If we take the entire length of the greater curvature as being represented by the number 100, the index of the cardiac sac portion is 52·4, and of the gastric tube 47·6.

The gastric tube is composed of two very nearly equal parts, viz. a portion formed by the body of the stomach and another which corresponds to the pyloric portion of the stomach. A bend in the tube, with a concurrent incisura angularis in the lesser curvature, indicates this subdivision, and opposite the incisura the greater curvature is pouched out into a distinct camera princeps, which gives rise to the increased girth at this point. The pyloric canal is expanded, and is thus not clearly marked off from the pyloric vestibule; but the duodeno-pyloric constriction is distinct and the sphincteric ring is firmly contracted. The part of the gastric tube which is formed by the body of the stomach is the most strongly contracted portion of the organ. It shows a gradual diminution in girth as it is traced to the right, and at its junction with the pyloric part its diameter is only slightly greater than that of the duodeno-pyloric constriction.

When the abdominal cavity of the subject in which this stomach was found was opened, only a small portion of the front wall of the cardiac sac immediately adjoining the constriction in the greater curvature was visible, below and to the right of the seventh and eighth costal cartilages of the left side. The remainder of the cardiac sac lay under shelter of the left lobe of the liver, the diaphragm, and the left thoracic wall. The tubular portion of the stomach was completely hidden from view by the transverse colon, which was placed in front of it, as so frequently happens in cases where the stomach is partially or completely empty. On pulling down the transverse colon, the

* The term "body of the stomach" (Magenkörper) is used here in the sense in which it is employed by His. He divides the stomach into a fundus, a body, and a pyloric part (22, pp. 347, 351, 352). The fundus and the body are separated by an imaginary line drawn horizontally around the organ from the cardiac opening to a point on the greater curvature directly opposite. To this encircling line His applies the term of zona cardiaca. The pyloric segment is marked off from the body of the stomach on the side of the lesser curvature by the incisura angularis; on the greater curvature side there is, as a rule, no sharp indication of such a subdivision. To render the division more precise, Müller draws a line from the incisura angularis to the most prominent point of the 'coude de l'estomac' or camera princeps; His, on the other hand, includes the whole of this bulging on the greater curvature in the pyloric part of the stomach—a subdivision which we prefer.

gastric tube was observed curving along the lower border of the left lobe of the liver, by which it was to a slight extent overlapped (Pl. III. fig. 24). A view of this stomach from behind, showing its relations to the liver and spleen, is exhibited in Pl. III. fig. 25. The manner in which the lesser curvature circumscribes the prominent and large tuber omentale of the liver on the under surface of the left hepatic lobe is seen. It will be further noticed that the sharp bend in the gastric tube takes place opposite the longitudinal fissure of the liver, and that the pyloric canal and the first part of the duodenum are directed backwards and upwards in contact with the lobulus quadratus.

Stomachs which present forms somewhat similar have been described by the late Professor BIRMINGHAM (2) in the admirable account which he has given of the digestive system. He regarded the condition as representing the typical state of the empty stomach. DIXON (12) has likewise exhibited at a meeting of the Anatomical Society the stomach of an adult male which presented a subdivision into a cylindrical and constricted part towards the pyloric end, and a dilated cardiac portion containing much milky food-material. He considered that the condition "might be taken to represent a possible normal temporary form of the stomach." The so-called systolic forms of stomach figured by PFAUNDLER (41) may also be said to have some features in common with the condition under consideration. But it is not necessary to restrict our attention to recent times, or, in other words, to the period during which formalin has been used as a preservative agent, to meet with references to stomach-forms which closely approximate to that which I have described. Such references are chiefly found in the literature which deals with bilocular or hour-glass stomach. More than half a century ago BROCA (5) gave an account of a stomach removed from a female criminal shortly after her execution, which exhibited a subdivision into a globular cardiac portion and a long intestiniform or tubular part, and he refers to a specimen of a similar kind which he had seen in a male criminal.

In an interesting paper published in 1883, Mr W. ROGER WILLIAMS (58) gives an account of ten cases of what he terms "congenital contraction of the stomach." His description is accompanied by outline drawings, and certain of these present a strong resemblance to the stomach-form under consideration. The description which he gives of his Case III. is also suggestive; he says: "The cardiac division was saccular in shape; the pyloric intestiniform—the latter being the larger and thicker." He is satisfied that all his specimens are to be regarded as instances of congenital deformity. He failed to find any pathological lesion at the site of the stricture, although in most he was able to detect in the neighbourhood of the lesser curvature certain suspicious indurations or scars at some little distance away. "I submit," he remarks, "that these appearances only admit of one explanation, namely, that the lesions were really caused by, and were secondary to, the contractions." But we need not dip further into the extensive literature on this subject. Enough has been said to show that the stomach-form exhibited in Pl. III. fig. 23 is one which has been noticed at odd times by numerous anatomists, although, from defective methods of preparation and the consequent failure

to preserve in every detail the proper shape of the organ, the full significance of the condition was not appreciated.

Under the heading of 'ausgeprägte Schnürmagen,' His (22) describes in his recent paper (p. 365) the stomach of a female which bears a striking resemblance to that under discussion. He has also published three photographs (Pl. XVIII.) and two casts of this specimen. Copies of the latter are in the Anatomical Museum of the Edinburgh University. One of these exhibits the organ after its removal from the abdominal cavity, whilst the other represents it from behind in its relation to the abdominal wall. The only essential points of difference between this stomach and the one I have described consist in: (1) its more perpendicular position; (2) its slightly smaller pouch-like cardiac sac; and (3) the more pronounced incisura angularis, and the more acute manner in which the gastric tube is bent on itself at this point. The subject from which this specimen was obtained showed a marked constriction of the waist, and His points out that this constriction of the body wall as seen from the interior corresponds with the constriction of the stomach. The words he uses are the following: "Die Abbildung zeigt links den Magen von der Rückseite her gesehen in Verbindung mit der vorderen Bauchwand, und sie lässt leicht die Beziehungen der Schnürfurche der Bauchwand zur Gestaltung des Magens verfolgen"; and then again: "An beiden Schenkeln des Magenschlauches bedingt die Schnürfurche eine Einbuchtung der Wand, sehr viel stärker allerdings am linken Schenkel." The two limbs of the stomach, to which he refers, are the two parts of the organ which are marked off from each other by the sharp bend in the gastric tube, and the deeper of the two constrictions is the deep notch in the greater curvature which indicates the separation of the cardiac sac from the gastric tube. From this description I think we may conclude that His was under the impression that the stomach-form to which he alludes is the result of tight-lacing or some other kind of compression applied to the lower costal arches. The view that the stomach may be divided into two parts or chambers by a localised contraction of its wall caused by compression of the lower portion of the thorax is not new. Indeed, it is of considerable antiquity, and some forms of hour-glass stomach have been accounted for in this way. Meckel (32) and Soemmerring (60) were exponents of this theory, and the former, in his work upon pathological anatomy, points out that many cases which had been considered to be congenital hour-glass stomachs were in reality due to mechanical causes operating from without. He adds: "So fand Reinmann den so abweichend gebildeten Magen bei einem Frauenzimmer, die beständig ein festes Schnürleib getragen hatte" (quoted from Kern (28)). Recently Rasmussen (43) and Chabrié (8) have strenuously supported this view. Most frequently, according to the latter writer, the biloculation is excited by costal pressure, but it may also be caused by the pressure of the liver or of its suspensory ligament.

The question before us, however, is not whether costal or other compression may provoke a response in the stomach by a localised contraction and constriction of its wall, but whether the stomach-form described by His can be explained in this way.

In so far as its division into a cardiac saccular part and a tubular part is concerned, only one answer can be given. Its striking resemblance to the stomach represented in Pl. III. fig. 23 points to the conclusion that both must be the result of the same cause, and in my specimen this cause was certainly not costal or any other form of compression. It was obtained from a male whose body wall was well formed, and in whom nothing abnormal could be detected in the abdominal contents. In His's case the doubling of the stomach upon itself and its vertical position were, however, no doubt due to the body constriction.

Such being the case, we must look for some other explanation which will account for a stomach-form which we shall see later is by no means uncommon.

Recent physiological investigation into the rhythmical movements of the stomach during the progress of gastric digestion affords us the key to the solution of the

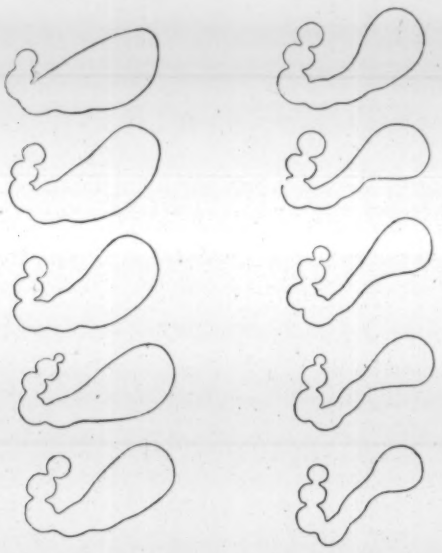


Fig. 1.—Some of the tracings which are given by Cannon to illustrate the forms assumed by the stomach of the cat during the progress of digestion.

problem. W. B. Cannon, of Harvard University (6), has written a most instructive paper on this subject, and has given us a very nearly complete picture of the motor activity of the stomach. His method of research consisted in feeding cats with a pulpy food impregnated with subnitrate of bismuth, a harmless, non-irritant powder, and then observing by means of the Röntgen rays the movements of the stomach as shown by the shadow of the food-mass thrown upon the fluorescent screen. Unfortunately, Cannon describes the stomach in a manner which does not appeal to the anatomist, but he supplies an excellent explanatory diagram, so that there is little or no difficulty in understanding the terms which he applies to the different regions of the organ.

According to Cannon, "the stomach consists of two physiologically distinct parts: the pyloric part and the fundus." The pyloric part, as understood by this author, comprises, in addition to the pyloric part as defined by the anatomist, the right half of the body of the organ; whilst the fundus is not limited below by the zona cardiaca,

but includes also the left portion of the body of the stomach. Over the pyloric part, which thus represents rather more than the right half of the stomach, "constriction-waves are seen continually coursing towards the pylorus." Each wave takes about thirty-six seconds to pass from the middle of the stomach to the pylorus, and the different waves follow each other at intervals of ten seconds. As they pass the incisura angularis, this indentation in the lesser curvature becomes deeper. The fundus (or left half of the stomach, as understood by CANNON) acts in a totally different manner. It "is an active reservoir for the food, and squeezes its contents gradually into the pyloric part."

The stomach is emptied by the conversion of the right half of its body into a tube, and over this constriction-waves are observed to pass. The rounded or spherical cardiac sac (CANNON's fundus), shows no peristaltic movement of its walls, but, by the firm, steady contraction of its musculature, its contents are by degrees pressed into the tubular portion of the stomach, and the whole length of this tube is "slowly cleared of food by the waves of constriction."

The investigations by ROSSBACH (45) into the movements of the stomach of the dog during digestion, undertaken eight years earlier, yielded results which closely correspond with those obtained by the more refined method of CANNON, but they differ in regard to the manner in which the stomach is emptied. ROSSBACH considers that during the whole period of gastric digestion the pyloric sphincteric ring remains closed, and only at the end of the process does it relax so as to allow the contents of the stomach to be discharged into the intestine. HIRSCH and CANNON, however, have brought forward very conclusive evidence to show that the discharge takes place intermittently—not at the approach of every wave, but at irregular intervals, according to the condition of the food which reaches the pyloric canal.

MM. JEAN-CH. ROUX and V. BALTHAZARD (46) have likewise, by the employment of the same method, obtained results which correspond very closely with those of CANNON, and especial interest attaches to the observations of these investigators, inasmuch as part of their work was carried out on the human subject. Their conclusions may be given in their own words (47): "Nous concluons donc que chez l'homme, comme chez le chien, comme chez la grenouille, au point du vue fonctionnel, l'estomac se devise en deux régions distinctes : la plus grande partie de l'estomac sert de réservoir aux aliments, la portion prépylorique est seul l'organe moteur de l'estomac, et par de violents mouvements péristaltiques, elle chase peu à peu dans le duodénum les matières accumulées dans l'estomac."

In the light of these investigations, I think that there can be little doubt that the stomach represented in Plate III. fig. 23 represents the functional phase so graphically described by CANNON, in which the organ is being gradually emptied. We have the spherical cardiac sac still holding a considerable amount of undigested food, and the long tubular part composed of two different portions of the stomach, viz. one formed by the right half of the body of the stomach (CANNON's preantral

part) and the other formed by the pyloric part (CANNON's antrum). If our interpretation of the form presented by this stomach be correct—and the striking manner in which it coincides in almost every particular with CANNON's description and figures would seem to exclude any other view—it is evident that even at the time of death the digestive movements of the stomach may under certain circumstances be carried on.

But many of the details given in the modern picture of the active stomach have been known for a long period of time. CANNON, indeed, makes no pretence that all the facts he brings forward are new; but to him is clearly due the credit of describing in a systematic and intelligent manner the proper sequence of the several events which mark the course of the motor activity of the stomach during the digestive process. Sir EVERARD HOME (23, 24, 25), while experimenting on the living dog, "found that the stomach, while digestion is going on, is divided by a muscular contraction into two portions; that next the cardia the largest, and usually containing a quantity of liquid in which there was solid food, but the other, which extended to the pylorus, being filled entirely with half-digested food of a uniform consistence." Again, in a paper published in the *Phil. Trans.* in 1807, he remarks that the human stomach is divided into a cardiac and pyloric portion by a muscular contraction similar to those of other animals.

In anatomical literature many references may be found which indicate this physiological division of the stomach. One example may be given. STRUTHERS (50), writing in 1851, describes a stomach presenting a constriction which "at first resembled the pylorus, the portion of the stomach beyond being intestiniform."

In BEAUMONT's classical observations (1) on Alexis St Martin, although we now know that erroneous conclusions were advanced as to the movements of the gastric contents, the description which is given of the various experiments indicates in the clearest manner the division of the stomach into a capacious left portion and an actively peristaltic tubular right portion. BEAUMONT records that on introducing a long glass thermometer through the fistulous opening it could be moved "freely in all directions in the cardiac portion"; but when pushed towards the pyloric portion it first met with some resistance, and then began to move with some force towards the pylorus. "These motions," he says, "are distinctly indicated and strongly felt in holding the thermometer between the thumb and finger; and it requires a pretty forcible grasp to prevent it slipping from the hand, and being drawn suddenly down to the pyloric extremity. When the thermometer is left to its own direction, at these periods of contraction it is drawn in, nearly its whole length, to the depth of ten inches, and when drawn back requires considerable force, and gives to the fingers the sensation of a strong *suction* power, like drawing the piston from an exhausted tube" (pp. 102 and 103). In another place he tells us (Experiment 79, p. 222): "This grasping sensation would continue for half a minute or more, and then appear to relax again." As already mentioned, CANNON has observed that in the cat it takes 36 seconds for a constriction-wave to pass along the whole length of the

gastric tube. But perhaps the experiment which conveys the clearest impression of the tubular form assumed by the right portion of the stomach during active digestion, and the powerful effect which its peristaltic contractions have upon its contents as these pass to and fro within it, is that in which he introduced into the stomach through the fistula six small muslin bags containing various articles of food, and arranged on a string at intervals of one inch from each other (Experiment 42, p. 268). "The bags seemed to have been as forcibly pressed as if they had been firmly grasped in the hand," and "in proportion as they had settled into the pyloric extremity."

As I have indicated, the stomach-form which we have had under discussion may be taken as the type of a series of stomachs which are not infrequently met with, and which all present very much the same general features. In the Anatomical Department of the University of Edinburgh there are ten such specimens, and, if these be arranged according to the shape exhibited by each, a more or less complete gradation from one form into another is seen, and an excellent idea of the manner in which the stomach becomes emptied is obtained. Several of these (Specimens III.^{A}, XIII.^{B}, I.^{B}, II.^{B}, III.^{B}) are depicted in Pl. III., and figs. 21, 22, 23, 29, and 31 may be compared in that order from this point of view.

Specimen III.^{A} is a full stomach obtained from a young adult male (Pl. III. fig. 21). From its form we may conclude that at the time of death the digestive process was in a state of abeyance, or was just on the point of beginning. A broad, shallow, annular constriction, most evident on the greater curvature, encircles the body of the stomach about its middle, and produces an indistinct subdivision of the organ into its two functional portions. This is not an unusual appearance to find in the full stomach.

Specimen XIII.^{B} presents an altogether different picture (fig. 22). It was obtained from an adult female. The position and relations which it exhibited within the abdominal cavity are seen in fig. 27. This stomach is obviously in the early stages of the emptying process.* The cardiac sac is relatively of great size and capacity, and was filled with a liquid grumous material which readily flowed out before the gelatine was introduced. In girth, the sac at the widest part is 250 mm., whilst it forms 260 mm., or 60·5 per cent., of the length of the greater curvature. The gastric tube is sausage-like, strongly curved upon itself, and its walls are firmly contracted. It forms 170 mm., or 39·5 per cent., of the length of the greater curvature, and is thus relatively short as compared with the gastric tube in Specimen I.^{B} (fig. 23). This shortness is due to the relatively small portion of the body of the stomach which has become tubular. At the junction of the gastric tube with the cardiac sac there is an annular constriction—very deep and distinct on the side of the greater curvature, but hardly perceptible on the lesser curvature. The incisura angularis is quite evident, and the pyloric canal is closed tightly along its whole length by the firm contraction of its sphincteric cylinder.

* A still earlier stage is seen in the stomach described by Dixon (12). He has been so kind as to furnish me with a drawing of this specimen, and from this it would appear that no part of the body of the stomach is involved in the formation of the tubular portion.

The stomach next in order in this series (Specimen I.[B], fig. 23) has already been fully described. It differs from Specimen XIII.[B] (fig. 22) in the relatively smaller size of the cardiac sac and the relatively larger portion of the body of the stomach which enters into the formation of the gastric tube.

Specimen II.[B] was obtained from an elderly female, and it is shown in its relations to the liver both from the front and from behind in figs. 26 and 29. Here a still greater reduction of the cardiac sac has taken place; but this shrinkage, as compared with Specimen I.[B] (fig. 23) is more in girth than in length. It is only 140 mm. in girth, whilst it forms 140 mm., or 56 per cent., of the length of the greater curvature. The gastric tube is narrow, with firmly contracted walls. It joins the lower end of the cardiac sac at a right angle, and is sharply marked off from it by a deep indentation in the greater curvature. It forms 110 mm., or 44 per cent., of the greater curvature. Its girth is very unequal at different points, due to three slight expansions of its wall, separated by two faint intervening constrictions. These suggest the constriction-waves described by CANNON as travelling over the gastric tube during the process of emptying of the stomach. The incisura angularis is not evident, and thus it is not possible to determine how much of the gastric tube is formed by the body of the stomach.

Specimen III.[B] was obtained from a young adult male. In fig. 30 it is seen *in situ*. When the abdomen was opened the transverse colon lay in front of it, and also occupied the vacant space which may be observed in the left hypochondrium. When the colon was pulled down, the only part of the stomach visible was the strongly contracted gastric tube extending downwards and to the right along the lower border of the left lobe of the liver. A view of this specimen as seen from above, after its removal from the abdomen, is given in fig. 31. Owing to the distended condition of the colon, the cardiac sac occupied an almost horizontal position; the fundus was directed backwards, and the long axis of the sac extended forwards, with a slight inclination downwards and to the left. The œsophagus opens into the upper surface of this portion of the stomach close to the lesser curvature. The girth of the cardiac sac is 157 mm., and the sac forms 170 mm., or 53 per cent., of the greater curvature. As in Specimen II.[B], the gastric tube leads out from the cardiac sac at a right angle. It is long and narrow, with firmly contracted walls; but as no incisura angularis can be detected, it is impossible to say to what extent it is formed by the body of the stomach. It forms 150 mm., or 47 per cent., of the length of the greater curvature of the stomach. At its extremity the pyloric canal turns sharply backwards.

The girth of the gastric tube is nearly uniform, but exhibits faint wave-like undulations along its whole length.*

* Two objections have been raised to the interpretation which has been offered regarding the nature of the stomach-forms which are described above. When the writer first introduced the subject at a meeting of the Anatomical Society at Oxford, it was suggested that the condition exhibited by the specimens might possibly be due to the action of the formalin which had been employed in the preservation of the subjects. Three arguments may be advanced against such a supposition, viz.: (1) that stomach-forms of a similar kind have from time to time been

An important question is suggested at this stage: To what extent is the body of the stomach, during the emptying process, converted into the tube over which the peristaltic waves pass? To judge from the specimen described by DIXON (12), the pyloric part of the stomach is in the initial stage of digestion alone tubular; then as the gastric contents begin to be discharged into the duodenum more and more of the body of the stomach is added to the tubular part, until a point a little beyond the middle of the stomach is reached. In the final stages the part of the stomach to the left of this, or in other words, the reduced cardiac sac, becomes more or less uniformly diminished by the steady contraction of its walls and by the passage of its contents into the gastric tube, but it does not itself become tubular. I have made the endeavour to illustrate this by measurement, but only with partial success, because the sequence is by no means perfect; although it will be seen that the main points are fairly well brought out.

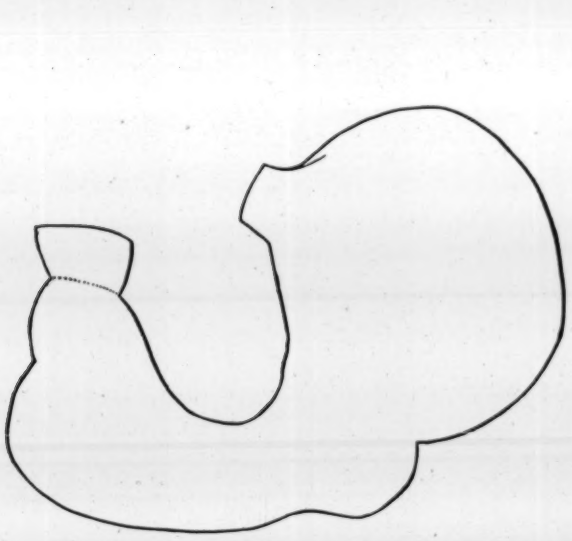


FIG. 2.

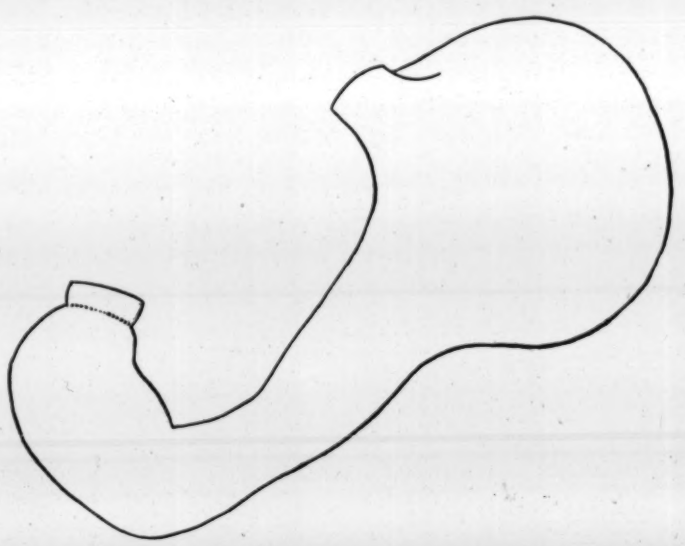


FIG. 3.

Figs. 2 and 3 represent two human stomachs, apparently perfectly healthy, which were obtained from two subjects shortly after death, neither of which had been treated by formalin or any preserving reagent. The outlines were obtained by placing the stomachs on paper and running a pencil around the margins. In both cases the pyloric canal was widely open, but the sphincteric ring tightly contracted.

observed before the introduction of formalin (see note at end of STRUTHERS' paper (50) on Double Stomach, also the description of some of the specimens in the paper by ROGER WILLIAMS (58, etc.); (2) that I have had brought to me several specimens straight from the post-mortem room which in all essential details are the same as those I have described (figs. 2 and 3); and (3) that it would be a very remarkable coincidence if, forty-eight hours after death (and often longer) the injection of formalin would produce a contraction of the stomach wall which reproduces in so remarkable a manner the form which has been shown by the physiologist to be distinctive of the organ during the more active phases of digestion.

The second objection is more plausible, but equally fallacious. It was advanced at a discussion which was held at a meeting of the Medico-Chirurgical Society of Edinburgh. It was then suggested that the appearances presented by the specimens might possibly be due to post-mortem rigidity. The third argument which I have employed against the formalin objection applies with equal force to this suggestion, and is to my mind unanswerable. PFAUNDLER (41) has investigated this matter, and has come to the conclusion that the contraction condition of the stomach is fixed at the time of death, and represents a permanent phase of its motor activity; and likewise that the *rigor mortis* of striped muscle has little in common with the stiffness so often noticeable in the stomach wall (see his remarks on this subject in page 13 of his work). I am not prepared to endorse this latter statement without further and more searching inquiry. The analogy which is sometimes drawn between the heart and the stomach in this respect is misleading, not only on account of the difference in the structure of the muscle-fibre in these organs, but also on account of the totally different character of the action and contraction periods.

Two sets of measurements were made in each case, viz. : (1) along the greater curvature, from the entrance of the œsophagus over the cardiac sac to the commencement of the gastric tube, and again from the latter point to the pylorus ; (2) along the long axis of the stomach from the summit of the fundus to the pylorus—measuring the cardiac sac and gastric tube separately. In dealing with these figures it is necessary to resolve them into percentages, because absolute measurements give no information on which a comparison could be established, seeing that the differences in the size of the stomach in different individuals is so great. In the following table, in which the results obtained from the seven best-marked specimens in my possession are given, it should be noted that the stomachs are arranged from above downwards in an order corresponding to the degree to which the emptying process has taken place. The first of the series (XIII.^{B}) is therefore the one in which this process has made least progress.

No. of Specimen and Sex.	Long Axis of Stomach.		Greater Curvature of Stomach.	
	Percentage formed by the Cardiac Sac.	Percentage formed by the Gastric Tube.	Percentage formed by the Cardiac Sac.	Percentage formed by the Gastric Tube.
XIII.^{B} ♀	51	49	60·5	39·5
I.^{B} ♂	46·8	53·2	52	48
VIII.^{B} (?)	41·3	58·7	48·8	51·4
II.^{B} ♀	47·2	52·8	56	44
VI.^{B} ♂	45·	55·	55	45
III.^{B} ♂	40·5	59·5	53	47
XIV.^{B} (?)	41	59	45·8	54·2

It is worthy of note that on the anterior and posterior surfaces of the contracted gastric tube the ligaments of HELVETIUS stand out much more distinctly than in those cases in which this part of the stomach is more or less expanded. This is apparently not due to contraction, but to the closer approximation of the fibres which compose them.

When all the contents of the stomach are discharged, the sharp distinction between the cardiac sac and the gastric tube may become in a measure lost through the strong contraction of the walls of the former, and perhaps a slight degree of relaxation of the latter. The stomach depicted in fig. 4 shows this condition. It was absolutely empty : indeed, no food had entered for some time before death, owing to the occlusion of the œsophagus through the pressure of a tumour. In other cases the collapsed cardiac sac may show a certain amount of infolding of its walls, due to the encroachment upon it of neighbouring viscera. The account given by BIRMINGHAM (2) of the empty stomach was not far from the truth, and he erred chiefly in failing to distinguish between the *emptying* and the *empty* stomach. It would, however, appear to be the rule, when the digestive process has come to an end, and all the gastric contents have been expelled into the intestine, for the gastric tube to become partially relaxed, to widen out somewhat, and to lose something of its firm and hard consistence.

Fœtus.—There is evidence that the fœtal stomach may show similar changes in form in correspondence with the motor activity of its muscular coat. I have examined seven full-term, still-born children from this point of view, and in two of these the stomach exhibited a subdivision into a cardiac saccular portion and a long tubular portion leading out from this. The best-marked specimen (VI.^{F}) is seen in fig. 28, Pl. III., and it will be observed that the separation is effected by a deep indentation in the greater curvature. In the second specimen (V.^{F}) the two functional portions of the stomach are likewise apparent, although the subdivision is less sharply indicated (fig. 32). In one of Erik Müller's figures of the fœtal stomach (40), a somewhat similar condition is depicted (see his Pl. X. fig. 7). It is very generally believed that in the later stages of intra-uterine life the fœtus swallows a considerable amount of the amniotic fluid (42). This no doubt excites the motor activity of the stomach and leads to the early delineation of its two physiological chambers. In one of the seven

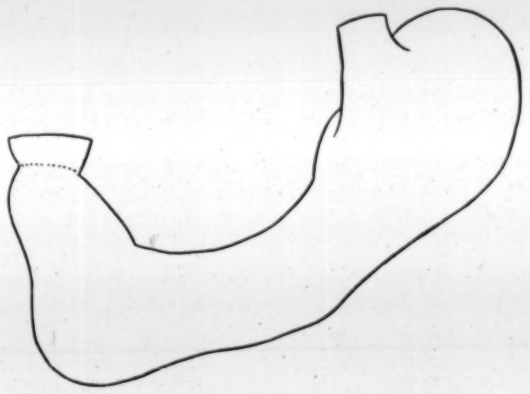


Fig. 4.—An absolutely empty Stomach.

specimens which I examined (VII.^{F}) the stomach was greatly distended with a thin turbid liquid mixed with mucus.

Certain Aberrant Forms of Stomach.

Amongst the numerous specimens which have come under my notice there are three aberrant forms (Specimens IV.^{B}, XI.^{B}, and V.^{B}), which have been much altered in form by excessive and probably badly co-ordinated contractions of the musculature. These stomachs are shown in Pl. IV. figs. 33, 34, and 35, and although at first sight they appear very different from each other, I have classed them together, because they exhibit, on closer inspection, certain common characters, which seem to indicate that in each case a common physiological cause has been at work. They all show an exceedingly deep incisura angularis and a doubling of the pyloric part upon the body of the stomach, and they all present in similar situations a corresponding series of expansions and constrictions, although these are expressed with different degrees of sharpness in the different specimens. Indeed, the correspondence between

these specimens brings forcibly before us the stereotyped character of the control which is exercised by the nervous mechanism upon the musculature of the stomach.

Specimen IV.[B] (fig. 33) was obtained in the dissecting-room from an adult female subject. The organ is bent acutely upon itself at the incisura angularis. The body of the stomach, which contained a small amount of contents, is divided by a notch in the greater curvature into two nearly equal parts. This indicates the physiological division of the stomach—the upper part being the representative of the cardiac sac, and the lower part representing the portion of the body of the stomach which contracts and enters into the formation of the gastric tube.

Specimen XI.[B] (fig. 34) was obtained from the post-mortem room. It is absolutely empty, and the same characters and subdivisions as in Specimen IV.[B] are visible. The extremely small size of the section which represents the cardiac sac is remarkable. This is due to the firm contraction of its walls. The separation of the body of the stomach into its two physiological portions is more clearly seen than in Specimen IV.[B], but the intervening constriction is broad and shallow; still, at this point the girth of the stomach is reduced to 90 mm. The part of the body of the stomach below this expands again until it attains a girth of 135 mm.

Specimen V.[B] (fig. 35), obtained from an adult male subject, presents some features of special interest. Specimens of a somewhat similar form have been described as multilocular stomachs. When compared with the two other forms with which it is associated (figs. 33 and 34), there is little difficulty in recognising that it exhibits precisely similar parts, although these are marked off from each other in a much more definite manner. The deep indentation in the greater curvature clearly indicates the lower limit of the cardiac sac: indeed, the general form of this upper section of the body of the stomach suggests its character. Between this and the incisura angularis, the lower part of the body of the organ shows a saccular expansion on the greater curvature, but nevertheless the general tubular form of the portion of the stomach formed by this and the pyloric part is apparent.

In Pl. IV. fig. 38 the interior of this specimen is seen, and the cut surface of its wall, which follows the outline of the two curvatures, shows some points of importance. The pyloric canal in its whole length is tightly closed and its passage occluded by longitudinal infoldings of the mucous membrane. This is brought about by the firm contraction of the thick sphincteric cylinder. Wherever a constriction in the wall of the stomach occurs, the circular muscular fasciculi will be observed to be greatly thickened at the bottom of the indentation. This is particularly noticeable in the case of the incisura angularis; but it can also be seen in the notch in the greater curvature which limits the cardiac sac below, and likewise to a less degree in the depression on the greater curvature opposite the incisura angularis. These thickenings of the circular coat are the result of strong contraction of the muscle-fasciculi, and in the same situations, but more especially in the deep furrow in the greater curvature between the two physiological portions of the stomach, the longitudinal fibres are also strongly contracted.

The different degrees of contraction exhibited by different portions of the muscular coat of this stomach were demonstrated in a striking manner by removing the mucous and submucous coats (fig. 40), and the part which the oblique fibres played in determining this stomach-form was rendered evident. The thick band of oblique fibres which forms a loop around the left side of the œsophagus, at the bottom of the incisura cardiaca, and which is carried on both aspects of the stomach to a point a little below and beyond the incisura angularis, was strongly contracted, and was clearly concerned in producing the doubling of the stomach upon itself.

It is manifest that the three aberrant forms which we have described not only present features in common with each other, but also with other stomach-forms which may be regarded as exhibiting a normal degree of motor activity: they are evidently in what KUSSMAUL (29) has termed a state of "peristaltic unrest." The conditions they represent are no doubt more or less temporary, but I am inclined to look upon them as abnormal, and in all probability caused by spasmodic contraction of the muscular coat. In cases of infantile pyloric stenosis exaggerated peristaltic constrictions with intervening bulging wave-like eminences can in certain cases be seen following each other over the surface of the abdomen in the region of the stomach. Several beautiful photographs of this are given by IBRAHIM (26). Specimen V.^{B} (fig. 35) is suggestive of such appearances.

HOUR-GLASS STOMACH.

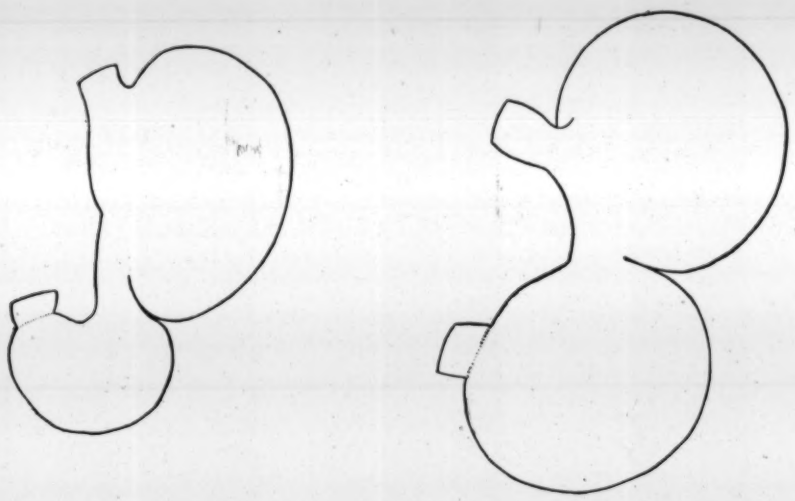
From the forms which we have had under discussion to the form known as hour-glass stomach is but a step. This is too large a question to enter upon at any length in the present communication; still, it is one which is so intimately connected with much that goes before that it is impossible to pass it over without touching upon certain points concerning it which are suggested by this investigation.

Although it is generally admitted that MORGAGNI (37) was the first who properly described the condition, the earlier anatomists were acquainted with the fact that it was not uncommon to meet with cases in which the stomach was divided more or less completely into two chambers. It has been customary to classify such stomachs into two groups, viz. (1) the acquired or pathological, and (2) the congenital.

The pathological group does not come within the range of this investigation. Every museum contains specimens which would seem to indicate that certain morbid conditions may, by adhesions, cicatrices, or otherwise, produce permanent localised contractions of the circular muscular fibres of the stomach, and thus a permanent division of the organ into two chambers which communicate with each other by a more or less narrow intervening passage.

In this country, the late Sir JOHN STRUTHERS (50) may be regarded as the leading exponent and advocate of the view that hour-glass stomach may occur as a congenital deformity, but recently the accuracy of this supposition has been strenuously called in question. MOYNIHAN (38 and 39), who has had a large experience from the pathological

side, writes as follows: "An examination of several specimens and an earnest search through the literature of this subject has convinced me that there is no proof whatever of the existence of an hour-glass stomach due to a congenital deformity. . . . So far as I am aware, there is not a single specimen or an accurate record in existence which can be accepted as evidence of the congenital origin of this disease." MOYNIHAN is not alone in this view; on the Continent the congenital explanation of certain forms of hour-glass stomach has never been received with the implicit faith which has been accorded to it in this country and (perhaps to a less extent) in America. CHABRIÉ and others not only deny the congenital origin of any form of the condition, but also call in question the accuracy of the view that pathological lesions are at any time responsible for the constriction.



A. B.

FIG. 5.—Two examples of Hour-glass Stomach.

A represents a specimen obtained from Professor ELLIOT-SMITH of Cairo. The connection between the two chambers is somewhat tubular.
B is the outline of a stomach obtained in the dissecting-room.
In neither case could the forefinger be passed with any degree of ease from the one chamber into the other.

For my own part, I am satisfied that hour-glass stomach never arises as a congenital deformity. With MOYNIHAN, I hold that not an atom of proof can be advanced in support of such a view. Still, there are many cases in which biloculation of the stomach occurs in which no pathological lesion of the kind mentioned by MOYNIHAN as being responsible for the condition can be detected. We have seen how, during the active stages of digestion, the stomach, by strong contraction of the walls of its right half, becomes differentiated into two physiological portions. Between this condition (fig. 23) and the bi-saccular state which is distinctive of the typical hour-glass form, in which there are two widely expanded sacs communicating by a narrow throat or cylindrical passage, every gradation may be met with. Compare from this point of view, and in the following order, fig. 23 (Pl. III.), the 'Schnürmagen' described by HIS (22; see his Pl. XVIII.), fig. 36 (Pl. IV.), and lastly the outline figs. A and B (fig. 5). In all these cases of what may be called physiological hour-

glass stomach, the subdivision takes place by a tucking-in of the greater curvature;* in no specimen belonging to this variety have I ever seen any indentation of the lesser curvature. When stomachs of this kind are opened up (Pl. IV. fig. 39), the mucous membrane at the place of constriction is seen to be thrown into closely set longitudinal folds, which may more or less completely occlude the passage from the one chamber into the other (see also His's Pl. XVIII.).

In all cases of hour-glass stomach included in this class the condition is due to a localised spasmodic contraction of the muscular coat. Most frequently this occurs at the site of the physiological subdivision of the stomach (*i.e.* about the middle of the body of the stomach), but it may also take place at any point between this and the pylorus. Moynihan gives a graphic account of the motor capabilities of the human stomach from this point of view. He says: "On several occasions during the last few years, when operating for chronic ulcer, I have watched the stomach intently for several minutes, and have seen the onset, the acme, and the gradual relaxation of a spasmodic muscular contraction of its walls. Quite gradually the stomach narrows and the wall becomes thicker and almost white in colour; when taken between the fingers the contracted area feels like a solid tumour. The spasm may be so marked as to prevent a finger being invaginated through the segment affected. The appearance presented is very striking. I have seen it in the body of the stomach and at the pylorus, but never at the fundus. As slowly as it comes on, the spasm quietly relaxes and the stomach assumes its natural form."

Every anatomist is familiar with corresponding spasmodic conditions of the intestine (Pl. IV. fig. 37). It is no infrequent occurrence to find two expanded pieces of intestine (either large or small) separated by a short piece of the gut so tightly contracted that it is reduced to the diameter of the little finger, and gives a hard and solid sensation when grasped between the finger and thumb. These are passing conditions in the intestine, and the question naturally suggests itself: Are the spasmodic local contractions of the stomach wall which separate the two relaxed chambers of an hour-glass stomach of the same kind? in other words, are these gastric states temporary and fleeting? Upon this point we have no proof, and I am not prepared to hazard an opinion on the subject. It is a problem which must be left to the clinician to determine.

Topography of the Stomach.

In the article by His (22) to which reference has been so frequently made, the topography of the stomach is very fully dealt with, and, as I find myself in general agreement with most of his results, it is unnecessary to dwell at any length on this aspect of the subject. A few observations supplementary to those of His are all that need be referred to.

* In this connection the diagrams given by Roux and Balthazard, showing the constriction-waves travelling along the greater curvature of the human stomach after the introduction of 15 to 20 grammes of subnitrate of bismuth suspended in 100 grammes of water, are very instructive (47).

His gives an admirable account of the position and appearance of the contracted stomach. The terminal part of the œsophagus takes a sharp turn to the left; the organ is bent on itself like a sickle, and the fundus sinks downwards so that it comes to look directly backwards; the surfaces look upwards and downwards and the curvatures forwards and backwards—the greater curvature being at a slightly higher level than the lesser curvature; lastly, there is a gradual but decided downward slope of the upper surface, which extends continuously from the fundus to the first duodenal curvature. All these features were evident in my specimens of the contracted stomach, and very markedly so in one of the two orangs which were examined. His does not enter into the conditions which give rise to this position and form of the stomach. These are sufficiently evident when the nature of the chamber within the abdomen which is occupied by the organ is considered. The roof of this chamber, formed by the liver and diaphragm, is more resistant, more unyielding, than the floor, which is formed to a large extent by the transverse meso-colon buoyed up by the movable coils of small intestine. As the stomach becomes empty and contracted, the intestines, acted on by the abdominal wall, rise up and press it against the sloping visceral surface of the liver, and the slope or gradual descent to the right which is so characteristic a feature of the upper surface of the stomach in this state is the result. The high position of the greater curvature and the bending of the lower end of the œsophagus are alike produced by the same cause.

His refers to the fact that the position of the empty stomach as described above is directly the opposite of what was formerly held to be the case. It has been usual to suppose that the contracted stomach was placed obliquely in the abdomen, and that as it filled it became more horizontal. In this connection I may be permitted to mention that about twelve years ago I made, by the reconstruction method, with the help of my friend and assistant, the late Mr John Stirling, a series of models of the viscera in the upper zone of the abdomen of a child, and in these the empty stomach presents a form and position in exact conformity with the description now given by His.

The picture given by His of the full stomach, whilst reproducing no doubt one type of the organ in this condition (and perhaps the more usual type), cannot be regarded as presenting the only position which is assumed by the viscus when it is filled. The leading points of his description are the following:—The fundus rises upwards, and in general form the organ becomes rounded; it assumes an oblique position, so that its surfaces look backwards and forwards; the pyloric part ascends to its termination, and the portion of the greater curvature formed by the pyloric vestibule (the camera princeps) takes a mesial position and occupies a lower level than any other part of the stomach.

Of seven specimens in my possession in which the stomach is more or less well filled, only one conforms with the above description. In the other six the expanded organ retains very much the position which we have seen is distinctive of the contracted stomach, with this exception, that, in the more pronounced cases of expansion, the

upper surface has lost to a great extent its downward slope to the right. Only that portion of the upper surface which remains in contact with the liver is oblique. For the most part both surfaces of the stomach are horizontal, and the greater curvature projects forward so as to press against the anterior wall of the abdomen (see Pl. I. figs. 9, 10, 11, and 12).

It is obvious, therefore, that His takes too limited a view of the possibilities of changes in the position and form of the full stomach. He does not sufficiently allow for altered conditions of surrounding viscera. In all cases the state of the movable, and as a rule yielding, floor of the stomach chamber has to be taken into account. It is possible that the easiest and most natural way for the stomach to expand, under ordinary circumstances, is in a downward direction by intestinal displacement, and when this occurs the oblique position of the organ described by His is the result. But when the intestines are distended the stomach cannot acquire the necessary space in this manner, and the liver, which forms so large a part of the roof of the stomach chamber, has to give way before it. Symington (52), several years ago, gave a convincing demonstration of the changes produced on the liver by the pressure of the stomach. The obvious result of such a condition of the intestine is that the full stomach retains the horizontal position. Although I do not possess specimens which exhibit intermediate conditions between the perfectly horizontal position and the oblique position of the full stomach, I have no doubt that such occur.

In the chimpanzee which was examined in connection with this investigation the stomach was well filled and had a horizontal position in every respect in close accord with the similar cases found in the human subject (Pl. I. fig. 13). In the second orang the stomach was slightly over-filled. It was oblique or almost vertical in position, and it was placed entirely to the left of the mesial plane (Pl. I. fig. 14). In this specimen, therefore, the stomach presented a condition in accord with that usually ascribed to the human fœtus.

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EXPLANATION OF PLATES.

Lettering common to all the figures :—

P.C. Pyloric canal.
P.V. Pyloric vestibule.
P.O. Pyloric orifice.
D.P.C. Duodeno-pyloric constriction.
S.C. Sphincteric cylinder.
S.R. Sphincteric ring.
B.S. Part of gastric tube formed by the body of the stomach.
O.F. Oblique muscular fibres of stomach.
T.F. Transverse or circular muscular fibres of the stomach.
D. Duodenum.

Plate I.

Fig. 6. The stomach of a full-time fœtus viewed from the front. It was hardened *in situ* by formalin injection. It shows very well the incisura angularis in the lesser curvature, the sulcus intermedius in the greater curvature, the pyloric canal and the pyloric vestibule. The arrows are directed towards the incisura angularis and the sulcus intermedius respectively. (Specimen F 2.)

Fig. 7. The stomach of a young chimpanzee viewed from above. The same specimen is seen *in situ* in fig. 13, and it will be observed that it is horizontal in position. The same characters are present in the pyloric part as in the specimen figured in fig. 6. Note, however, the small size of the pyloric vestibule, and also the large size of the fundus.

Fig. 8. The stomach of a male child two years old viewed from above. The same specimen is figured *in situ* in fig. 11. It shows particularly well the incisura angularis, the sulcus intermedius, the duodeno-pyloric constriction, the pyloric canal, and the pyloric vestibule. (Specimen I.[A])

Fig. 9. Child from nine months to one year old. The stomach is moderately full and horizontal in position. The greater curvature is higher than the lesser curvature, the organ is bent on itself like a sickle, and there is a gradual descent or slope from the fundus to the junction of the first and second parts of the duodenum. In other words, the position is identical with that described by His as characteristic of the empty stomach.

The liver is pushed somewhat to the right, and the transverse colon was in contact with a portion of its under surface in front of the stomach.

In this specimen the intestines were much distended. (Specimen II.[A])

Fig. 10. Same specimen as shown in fig. 9, with the liver removed.

Fig. 11. Child of two years. Note the horizontal position of the stomach, the greater curvature of which looks straight forward and the surfaces upwards and downwards. The stomach is moderately full and the liver pushed to a considerable extent to the right. The intestines were distended, and formed with the transverse meso-colon a horizontal platform on which the stomach rested.

Fig. 12. Young male in which the stomach, which is full, holds an absolutely horizontal position. The liver is pushed over to the right. (Specimen III.[A])

Fig. 13. Young male chimpanzee with a full stomach. The position is identical with that seen in the child of two years old (fig. 11).

Fig. 14. Young orang-utan with well-filled stomach. The position of the stomach is peculiar. It lies entirely to the left of the mesial plane and is very nearly vertical.

Plate II.

Fig. 15. Section through the pyloric canal and pyloric vestibule of the stomach of the chimpanzee (fig. 7) in the plane of the two curvatures. It is enlarged by one-half. The arrow points to the sulcus intermedius.

Fig. 16. Section through the pyloric canal and pyloric vestibule of the stomach of a child two years old (fig. 8) in the plane of the two curvatures. It is enlarged twice the size of nature. The arrow points to the sulcus intermedius. (Specimen I.[A])

Fig. 17. Micro-photograph ($\times 10$) of a preparation by Mr Stiles. It is taken from a microscopic section through a portion of the pyloric canal and of the duodenum of a full-time fœtus. The characters of the sphincteric cylinder and ring, and the relation which the longitudinal fibres present to these, have been slightly accentuated by the brush. In this photograph the pyloric canal is to the right, the duodenum to the left, and the lesser curvature margin of the section is the upper of the two.

Fig. 18. Micro-photograph of a section through the pyloric canal and commencement of the duodenum, in the plane of the curvatures of the stomach, of an infant a few weeks old. The original photograph magnified the specimen five times, but in the plate the magnification is only $\times 3\frac{1}{2}$. The characters of the sphincteric cylinder and ring, and the relations which the longitudinal fibres present to these, have been slightly accentuated by the brush. Note that the pyloric canal is to the right, the duodenum to the left, and that the lesser curvature margin of the section is the upper of the two.

Fig. 19. Micro-photograph of a section through the pyloric canal and commencement of the duodenum of an infant a few weeks old, with stenosis of the pylorus. The original magnification was $\times 5$, but in the plate it is only $\times 2\frac{1}{2}$. The characters presented by the musculature have been slightly accentuated by the brush. When this figure is compared with figs. 17 and 18, and account is taken of the lower magnification, the hypertrophy of the muscular tissue—both circular and longitudinal—becomes apparent. If anything, the hypertrophy is more marked in the longitudinal coat of the pyloric canal. It should be observed that the pyloric canal in the photograph is to the right, the duodenum to the left, and that the lesser curvature margin of the section is the upper of the two.

Fig. 20. Micro-photograph of a section through a small part of the pyloric canal and the commencement of the duodenum of the cat. Magnification × 5. The pyloric canal is to the right, the duodenum to the left, and the lesser curvature margin of the section is the upper of the two. The strong differentiation of the sphincteric ring on the greater curvature side is very evident.

Plate III.

Fig.-21. The stomach of a young male viewed from the front and slightly from above. The characters which it presents are referred to in the text at p. 32. Note the strongly marked ampulla phrenica on the part of the œsophagus immediately above the œsophageal opening of the diaphragm. (Specimen III.[A])

Fig. 22. Stomach of an adult female in the early stage of the emptying process. It is described in the text at p. 32. The arrow is directed towards the incisura angularis. In fig. 27 this stomach is seen *in situ*. (Specimen XIII.[B])

Fig. 23. Stomach of an adult male showing very clearly the physiological subdivision into a cardiac sac and a gastric tube. It is described in the text at p. 33. This specimen is seen *in situ* in fig. 24. (Specimen I.[B])

Fig. 24. The same stomach as is depicted in fig. 23, exhibited *in situ*. The transverse colon, which lay in front of the stomach and also to some extent in front of the liver, has been pulled down.

Fig. 25. The same specimen as is figured in fig. 23, seen from behind and in relation to the liver and spleen. The manner in which the tuber omentale of the liver occupies the lesser curvature of the stomach is well seen.

Fig. 26. The stomach of an adult female viewed from the front, in which the emptying process has proceeded to a greater extent than in fig. 23 (see text, p. 33). It is shown in relation to the liver. (Specimen II.[B])

Fig. 27. The same stomach as is seen in fig. 22 *in situ*.

Fig. 28. The stomach of a full-time fœtus, showing the physiological subdivision into a cardiac saccular portion and a tubular portion. (Specimen F 6.)

Fig. 29. The same specimen as is represented in fig. 26 seen from behind. (Specimen II.[B])

Fig. 30. The specimen which is exhibited in fig. 31 shown *in situ*. The transverse colon lay in front of the stomach and occupied a considerable part of the left hypochondrium. It has been drawn down.

Fig. 31. The stomach of a young adult male, viewed from above, in which the emptying process is nearly completed (see text, p. 33). It is seen *in situ* in fig. 30. (Specimen III.[B])

Fig. 32. The stomach of a full-time fœtus in which the physiological subdivision into two parts is seen. Note the flattening of the œsophagus from the pressure of the heart and pericardium. (Specimen F 5).

Plate IV.

Fig. 33. Stomach of an adult female; aberrant form. Described in the text at p. 37. (Specimen IV.[B])

Fig. 34. Specimen obtained from the post-mortem room (sex?). It is described in the text at p. 37. (Specimen XI.[B])

Fig. 35. Stomach of an adult male; aberrant form. Described in text at p. 37. (Specimen V.[B])

Fig. 36. Specimen obtained from the post-mortem room (sex?). It exhibits a form intermediate between that seen in the stomach represented in fig. 23 and that of a true hour-glass stomach (Specimen X.[B])

Fig. 37. A portion of the transverse colon of a young orang in which a short part is contracted so firmly that it feels perfectly solid. This is a transitory spasmodic contraction.

Fig. 38. Section through the stomach figured in fig. 35 along the plane of the curvatures. The interior of the posterior half is shown. The characters of the pyloric canal, the pyloric vestibule, and the thickening of the muscular coat at the bottom of the sulci due to contraction are well seen.

Fig. 39. The anterior half of the stomach depicted in fig. 36, to show the manner in which the mucous membrane is disposed in longitudinal folds at the seat of the constriction or indentation in the greater curvature. Observe the tight closure of the whole length of the pyloric canal through firm contraction of the sphincteric cylinder.

Fig. 40. This figure shows the muscular fibres of the anterior half of the stomach represented in fig. 35. The mucous membrane and the submucous coat have been removed from the interior. A striking demonstration is obtained of the thickening of the circular fasciculi, through contraction, at the bottom of the various indentations, and also of the strongly contracted oblique fibres. A beautiful view is also afforded of the contracted pyloric sphincteric cylinder and ring. On referring to fig. 38, it will be seen that the pyloric canal is almost closed by longitudinal folds of mucous membrane. The arrangement of the longitudinal pyloric fibres with reference to the sphincteric ring is likewise exhibited. The arrows are directed towards the incisura angularis and the sulcus intermedius respectively.

CUNNINGHAM: VARYING FORM OF THE STOMACH IN MAN AND THE ANTHROPOID APE.

Plate I.

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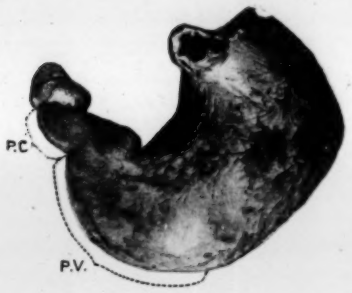

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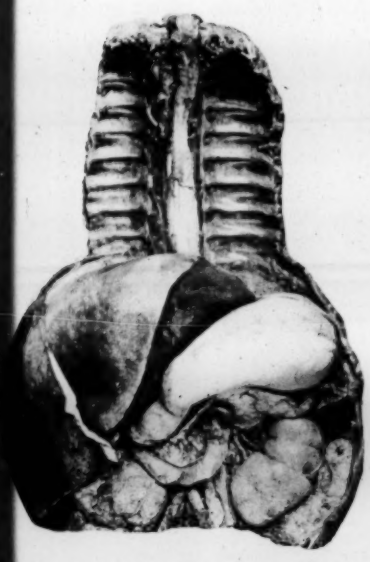

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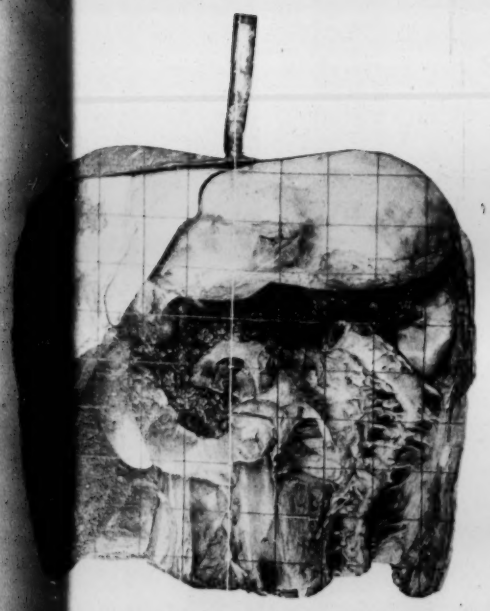

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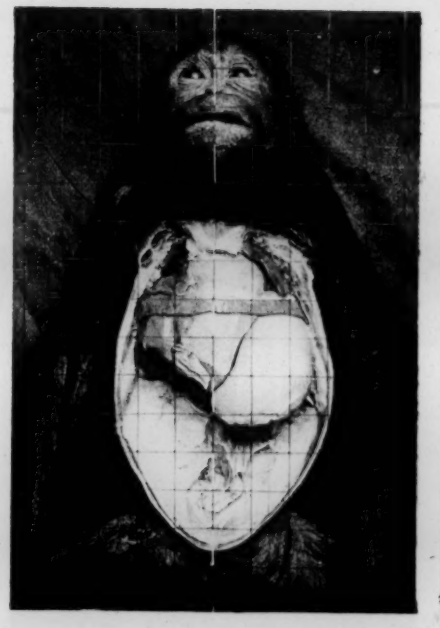

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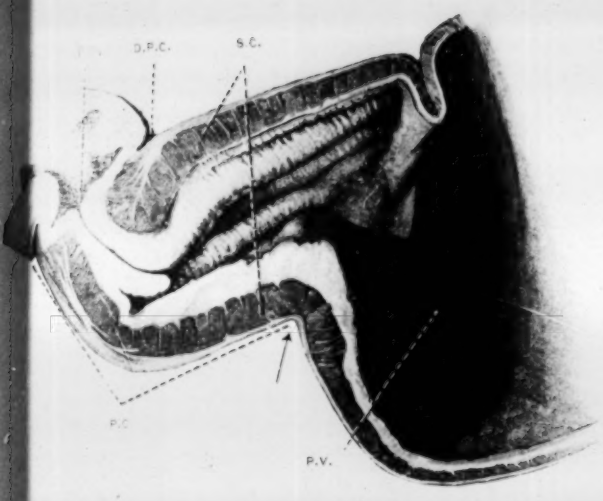
CUNNINGHAM: VARYING FORM OF THE STOMACH IN MAN AND THE ANTHROPOID APE.

Plate II.



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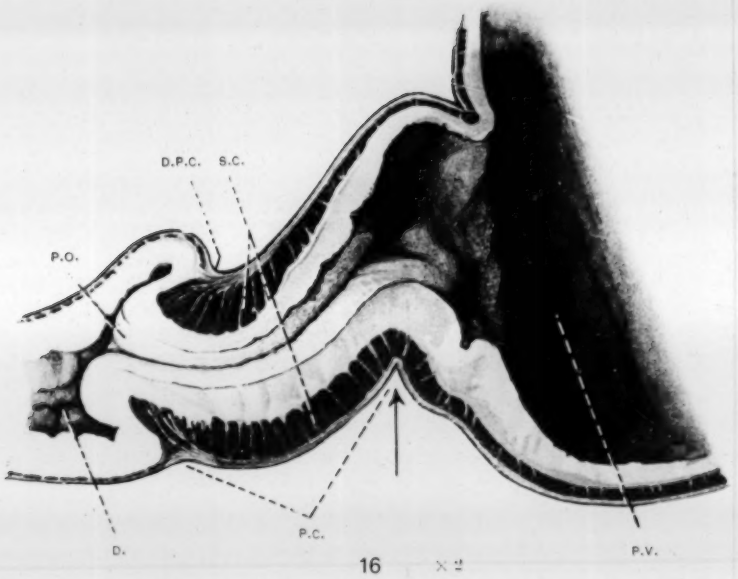

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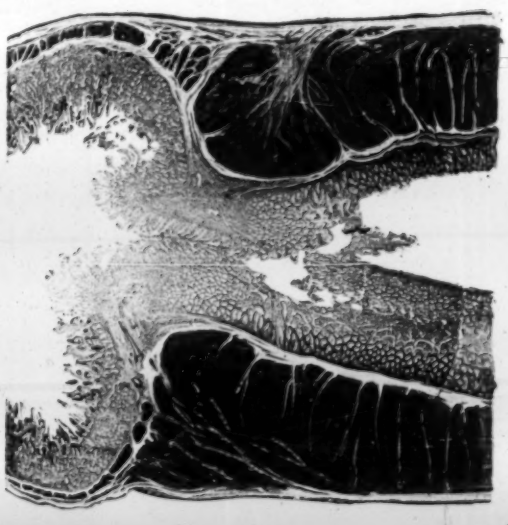

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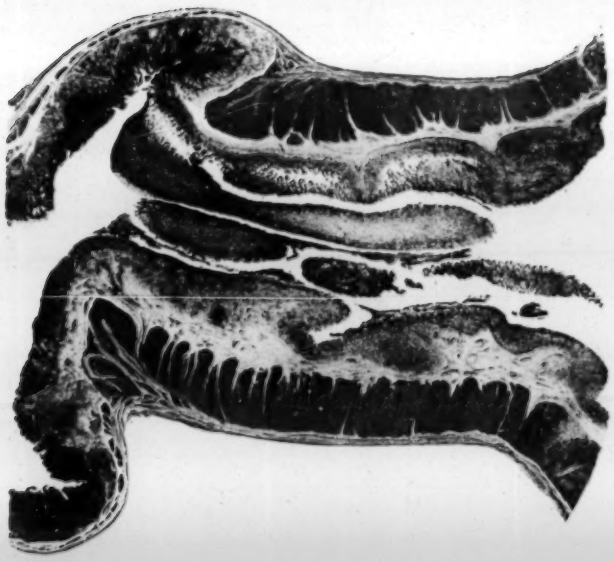

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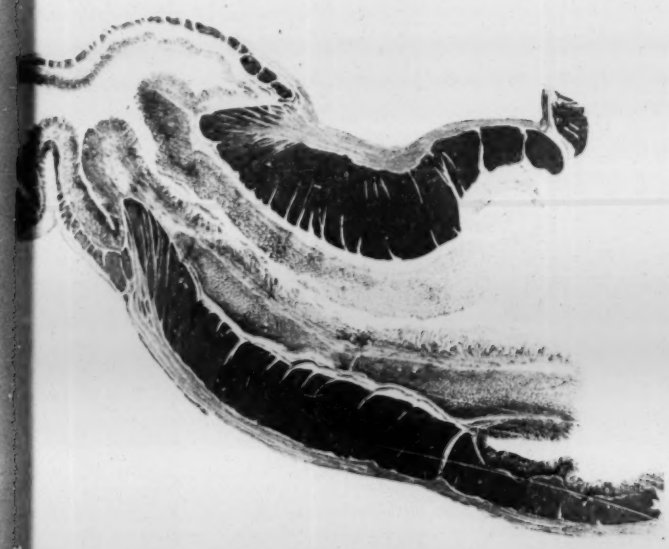

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CUNNINGHAM: VARYING FORM OF THE STOMACH IN MAN AND THE ANTHROPOID APE

PLATE III.

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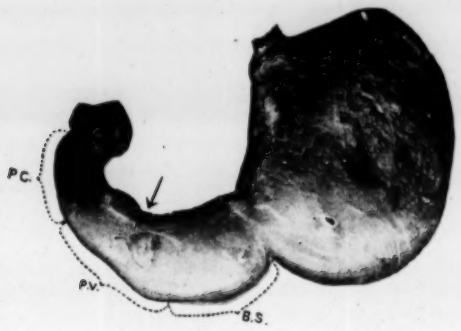

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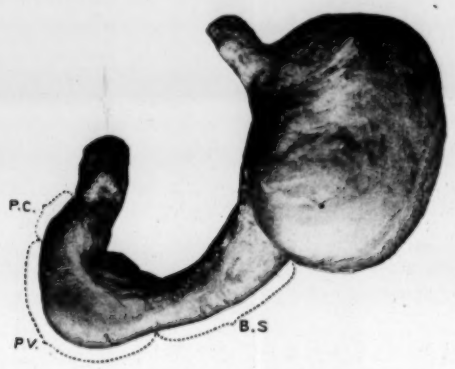

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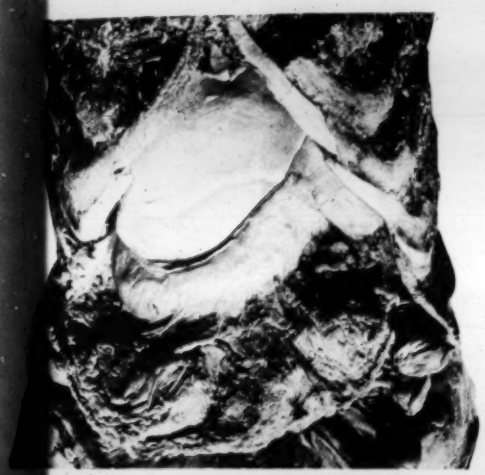

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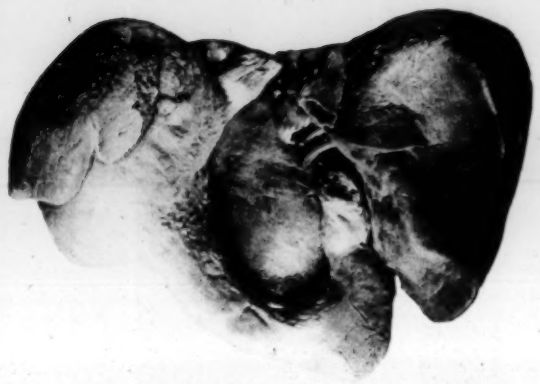

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CUNNINGHAM: VARYING FORM OF THE STOMACH IN MAN AND THE ANTHROPOID APE.

PLATE IV.

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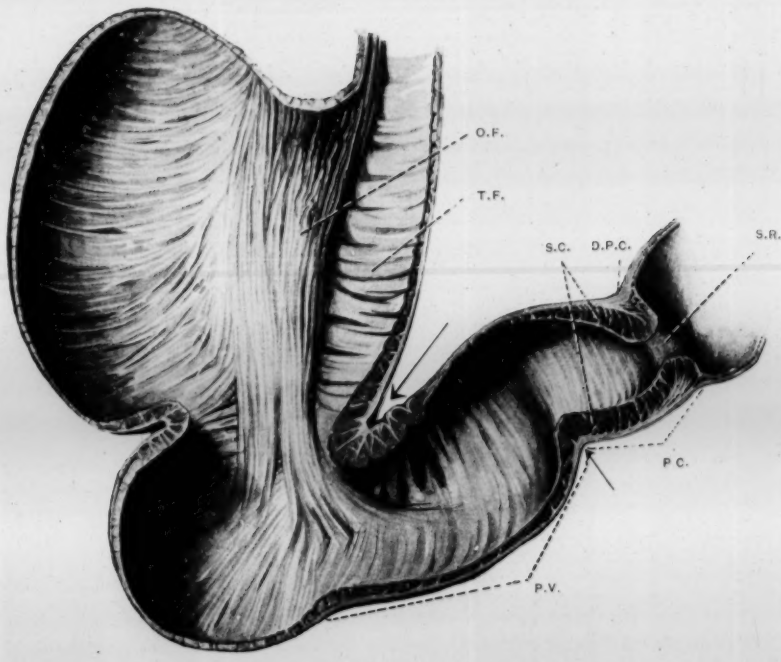

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III.—The Development of the Skull and Visceral Arches in Lepidosiren and Protopterus.

By **W. E. Agar**, B.A., Junior Demonstrator in Zoology at Glasgow University. *Communicated by* Professor J. Graham Kerr, M.A. (With Three Plates.)

(MS. received November 8, 1905. Read December 4, 1905. Issued separately August 15, 1906.)

The material for this work was that collected and prepared by Professor J. Graham Kerr in the Chaco (*Lepidosiren*), and by Budgett from the Gambia (*Protopterus*). The process of development follows nearly the same course in the two genera, and where differences occur they are mainly such as are to be expected from a comparison of the adult skulls. While the series of stages of *Lepidosiren* left no unfilled gaps, the material was scantier in the case of *Protopterus*. Except where otherwise stated, the detailed descriptions were worked out in *Lepidosiren*, but whenever I was unable to verify that the process was substantially the same in the other genus, the fact has been mentioned. The stages are numbered in correspondence with the stages figured by Graham Kerr (*Phil. Trans. Roy. Soc.*, B., vol. cxcii.). The *Protopterus* stages are numbered the same as the corresponding ones in the other genus. As far as possible, the nomenclature adopted by Gaupp * has been adhered to.

Throughout this work I have been indebted to Professor Graham Kerr for much advice and criticism.

The *Notochord* arises from the dorsal wall of the Archenteron,† at first continuous with the mesoblastic rudiment, at about stage 14. It remains in contact with the hypoblast till about stage 24. In stage 23+ the notochord can be seen running forward beyond the front end of the auditory sac. Its anterior end, however, has not the characteristic histological arrangement of the chordal cells, as vertically placed discs, which obtains in the other parts of the notochord at this stage, and soon disintegrates and becomes mesenchymatous in appearance. Before this takes place the primary sheath (elastica externa) has been secreted, so that after the front part of the chorda has disappeared the sheath is left projecting for some way beyond the definitive front end (fig. 1). In consequence of this, although in stage 23 + the front end of the notochord was in front of the auditory sac, in stage 29 it is about ·3 mm. behind it, though the sheath is traceable for a short distance further forward. There is, of course, a certain amount of tissue inside this part of the sheath, but it is exactly like the mesenchyme surrounding it. The definitive notochord can be seen ending quite sharply behind this tissue (fig. 2). In stage 31 (fig. 3) the notochord can be seen growing forward again into this part of the sheath. The advancing tip is pushing

* "Die Entwickelung des Kopfskeletes," in O. Hertwig's *Handbuch.*

† Graham Kerr, *Quart. Journ. Micr. Sci.*, vol. xlv. part i.

forward the loose tissue inside it, so that the latter has accumulated into a thick mass of heavily yolked material in front of the growing point. As if owing to the pressure thus set up, the front end of the notochord ends squarely against the accumulating yolk and other tissue in front of it. Fig. 4, about stage 32, shows the continuation of this process. The secondary or fibrous sheath has been secreted internally to the elastica externa. Finally, in stage 38 (fig. 5), we see an extremely dense mass, representing the massed-up tissue pushed forward by the advancing notochord, enclosed in the extreme front end of the primary sheath. Figs. 2, 3, 4 and 5 are drawn under the same magnification, and show the forward growth of the notochord towards the pituitary body. That the diminishing distance between these two structures is due to the moving forwards of the tip of the notochord, and not only to the backgrowth of the pituitary body, is shown by comparison with other structures, such as the auditory sac and parts of the skull. The growth of the notochord is evidently brought about partly by the vacuolisation of the heavily yolked cellular material occupying the front end (*cf.* figs. 2, 3, 4, 6 and 5, showing this proceeding *pari passu* with the absorption of the yolk). At the same time, of course, the whole notochord increases in length by the enlargement of the vacuoles throughout the structure.

Fig. 6 is drawn under a higher power to show the relations of the sheaths. Both these are fully differentiated before the outer cells of the chorda have arranged themselves into an epithelium, which takes place about stage 36+. After the formation of the epithelium the secondary sheath increases very rapidly in thickness, especially its outer layer. Immigration of cartilage cells from the bases of the arcualia begins about stage 36.

It is interesting to note that the part of the primary sheath in front of the re-advancing tip of the definitive notochord increases, probably in length, and certainly in thickness, though far removed from any epithelial influence.

The foregoing account applies to *Lepidosiren*. In *Protopterus* I was unable to make out the details of the process. The anterior end of the notochord recedes, however, between stages 25+ and 28+, and then grows forwards again. The whole process takes place much more rapidly in *Protopterus* than in the other genus, and is practically complete in stage 32.

The first appearance of the cranium is in stage 31, where the *trabeculæ* are represented by concentrations of connective tissue underlying the thalamencephalon and mid-brain; near their hind ends each is continuous with a downward extension of this tissue, the *quadrate*. The *hyoid arch* is also foreshadowed in connective tissue.

Fig. 7, Plate II., and fig. 13, Plate III., show a reconstruction from horizontal sections of a slightly later stage in *Protopterus* (about stage 31). This and all the other reconstructions were made by GRAHAM KERR'S method. The only material difference between this and the corresponding stage in *Lepidosiren* is that in this genus the notochord does not extend so far forward at present. As already mentioned, the re-growth forward of the notochord takes place much more quickly in *Protopterus*. At this stage the conversion

of the membraneous tissue of the previous stage into cartilage is beginning. In the figure only those parts of the cranium marked out by the commencement of this process are shown. Consequently the outlines are somewhat arbitrary at the hind end of the figure. The figures, however, show all those parts of the skull which have arrived at the same stage of histogenesis.

The front end of each trabecula now takes the form of a somewhat thin lamina of prochondral tissue, inflected at its lower margin, following the contour of the thalamencephalon. The optic nerve runs in front of the abrupt edge of this lamina. At its extreme anterior end each trabecula is produced into a flattened dorsal spine, on the outer side of which runs the ophthalmicus profundus branch of the fifth nerve* (v.^{1}, figs. 7 and 13). For the sake of convenience this spine may be called the *orbito-temporal process.* Close behind this each trabecula is provided with a triangular horizontal shelf projecting externally. This is the floor of the front end of the *Gasserian recess* (the name given by BRIDGE † to the cartilaginous recess lodging the very large ganglionic mass representing the ganglia of v., vii., and vii. lateralis). Behind this shelf two nerve trunks pass over the trabecula—the superior maxillary branch of the fifth nerve (v.^{2}, figs. 1 and 5), and a composite nerve consisting of the inferior maxillary branch of the fifth, and the buccal and superficial ophthalmic branches of the seventh nerve (v.^{3}, vii. lat.).

The hinder part of the skull rudiment on each side extends further posteriorly than in the previous stage, the new part representing the *Balkenplatte* (STÖHR) portion of the parachordal cartilage. The wide separation of the Balkenplatte of each side from the notochord is noteworthy. The position of the auditory capsules is indicated in fig. 7 in section. They at present show hardly any signs of chondrification. There is at present no indication of the occipital portion of the parachordals.

The rudiment of the quadrate cartilage is from the first continuous with the trabecula by a process which the disposition of the nerves shows to be the *Processus basalis.* In this respect the Dipneumona contrast with the more primitive condition found by SEWERTZOFF ‡ in *Ceratodus*, where the quadrate is at first free from the trabecula. The hyoideo-mandibular nerve runs ventralwards behind the basal process (figs. 7, 13, vii. hyo.). Separated from the quadrate by a region of more embryonic tissue is Meckel's cartilage. This does not yet meet its fellow in the middle line, nor does the hyoid arch. The latter shows no signs of segmentation at this or any other stage, nor was the hyo-mandibular, found by SEWERTZOFF (*loc. cit.*) in *Ceratodus* and confirmed by K. FÜRBRINGER, § observed at any stage.

A strand of dense connective tissue, connecting the distal end of the rudiment of the quadrate with that of the palatine tooth, probably represents the vestige of the palato-pterygoid cartilage (fig. 13). At its hind end it passes directly into the substance of the

* PINKUS, "Die Hirnnerven des Protopterus annectens," *Morph. Arb.*, Bd. iv. 1895.
† *Trans. Zool. Soc.*, 1898. ‡ *Anat. Anz.* Bd. xxi., 1902.
§ *Beiträge zur Morphologie des Skeletes der Dipnoer*, 1904.

prochondral quadrate. As this is a very evanescent structure, it will be best to follow its fate at once. At this stage (about 31) there is no bone present either in the tooth or in the connective tissue (fig. 10). In stage 31 + bone has been deposited in the tooth rudiment and spreads a short distance back along the inner side of the connective tissue strand. [GRAHAM KERR* has described the development of the teeth in *Lepidosiren*, and showed that they develop from a continuous rudiment, and are not formed by the fusion of separate denticles as in *Ceratodus* (SEMON)]. In stage 34 the bone has grown back from the tooth along the connective tissue to the inner side of the quadrate, which it overlaps (fig. 11). The above series refers to *Protopterus*, but would apply almost equally well to *Lepidosiren*. In the earliest larva of this genus, however, in which ossification was found, this was not taking place in the tooth germ but dorsal to this, in the part of the bone which in the adult forms the ascending process (*cf.* fig. 16, Pl. III.). The early appearance of calcareous matter in this region may probably be ascribed to the fact that this part of the bone is the thickest in the adult. Almost simultaneously with its appearance the bony trabeculæ in the tooth are formed, and become continuous with it, and the whole bone begins to grow back. It is significant that the connective tissue is not merely ossified, but that the bone grows back from the tooth along its inner side (fig. 12). This is also shown by the fact that whereas in stage 31 the connective tissue strand passes directly into the anterior face of the quadrate, the bone when formed, that is, about stage 32+, overlaps this on its inner side and is only loosely attached to it here (*cf.* figs. 10, 11). The connective tissue never shows any sign of chondrification, so if it represents the palato-pterygoid cartilage, it must be in a very vestigial condition. It is replaced by bone before the quadrate itself is out of the prochondral stage.

This bone shows no indication in its development of being composed of separate palatine and pterygoid elements, although, according to GÜNTHER,† the suture between the two constituents is traceable in the adult *Ceratodus*.

At a slightly later stage than that figured in figs. 7 and 13, the hinder parts of the skull basis appear in the form of a pair of neural arches, which will subsequently form the *occipital arches*. Their bases are prolonged forward for a short distance on each side of the notochord as the *occipital plates*.

The only other changes to be noticed are the appearance of the palato-pterygoid bone (just described), the parasphenoid, and the splenial. The *parasphenoid* takes the form of two longitudinally running bones, stretching from the region of the attachment of the quadrate to some way in front of the first neural arch (future occipital arch). The bones are widely separated from each other by the hypophysis, which is only just losing contact with the pharynx. In front they are flattened horizontally, but further back take the form of almost circular rods. The parasphenoid is paired at first in *Protopterus* also.

The mandibular tooth is now forming, and a short flat process is growing back from its base along the inner side of Meckel's cartilage—the rudiment of the *splenial*.

* *Quart. Journ. Micr. Sci.*, vol. xlvi. † *Phil. Trans. Roy. Soc.*, 1871.

The general structure of the skull at stage 34 is shown in figs. 8 and 14, Plates II. and III., from reconstructions from horizontal and sagittal sections respectively. It will be convenient to begin the description from the hind end.

The *occipital arch* is still an obvious neural arch, only distinguished from the succeeding ones by its greater size. There is a wide gap between this arch and the next one (first neural arch proper). Two nerves leave the spinal column through this space, marking the loss of an arch between them. In no stage in *Lepidosiren* could I find a trace of this arch, but it is present in a more or less vestigial condition in *Protopterus* (fig. 15). In *Ceratodus* this arch is present throughout life, but remains unossified (K. FÜRBRINGER). The two nerves mentioned are *a* and *b* of M. FÜRBRINGER.* As a matter of fact, in *Lepidosiren* the posterior limit of the skull is sharply defined by the gap between the occipital and the first true neural arches, and this boundary is also clearly marked in the adult, so that unless the parasphenoid determines the backward extent of the skull, the nerves should perhaps be called 1 and 2. These nerves in *Protopterus* become included in the occipital region of the adult (FÜRBRINGER, and *cf.* fig. 15 for *a*).

The *occipital plate* has grown forward from the base of each arch along the side of the notochord towards the Balkenplatte, with which, however, it has not yet fused. The occipital plates of the two sides are as yet unconnected dorsally or ventrally. Between the occipital arch and the vagus the occipital nerves leave the skull. Of these there are usually two (*y*, *z*), sometimes three (*x*, *y*, *z*) in *Protopterus*. In no stage of *Lepidosiren* have I found the nerve *x*, nevertheless at this stage (34) in both genera the myomeres corresponding with the three nerves are present (fig. 8). I have designated the myomeres X, Y, Z, etc., in correspondence with the neuromeres *x*, *y*, *z*, etc. The occipital arch is thus in the septum between the third and fourth metotic myomeres. I hope to return to these nerves and myomeres in a subsequent paper. No traces of those arches in front of the occipital arch, whose loss is indicated by the myomeres X, Y, Z, could be discovered. Immigration of cartilage cells into the chordal sheath, which takes place at a later stage, also proceeded irregularly without any indication of metameric divisions.†

SEWERTZOFF finds that in the second stage of *Ceratodus* figured by him the occiptal arch is in the septum between the fifth and sixth myomeres. He supposes that these myomeres are Y and Z, but K. FÜRBRINGER finds an additional nerve in front of that identified by SEWERTZOFF as *x*, and from other considerations also proves beyond doubt that this arch separates the myomeres Z and A. Thus in the earliest stage in which the occipital arch is present, *Ceratodus* possesses five myomeres in front of this arch (V, W, X, Y, Z), and the Dipneumona in the same stage only three (X, Y, Z). At the stage in question, even in *Ceratodus*, V and W have begun to degenerate.

The portions of the myomeres X, Y, Z, shown in fig. 8, lie close alongside the

* Ueber die Spino-occipitalen Nerven der Selachien, etc., *Fest. für Gegenbaur*, 1897.

† In *Lepidosiren*. In *Protopterus* I had no stage showing the process of this immigration.

notochord, and the anterior ones penetrate the connective tissue connecting the Balkenplatten and occipital plates. On the chondrification of this tissue these parts of the myomeres completely disappear, while a small artery, given off from the root of the aorta and entering the cranial cavity, is enclosed by the cartilage (figs. 8 and 9).

The dorsal end of the occipital arch is not yet fused with the auditory capsule, but is attached to it by a strand of prochondral tissue. This strand is really a backward continuation of the auditory capsule. Into it projects the posterior vertical semicircular canal. In progress of development chondrification proceeds from the auditory capsule back along this strand, which at the same time increases in vertical extent and receives more and more of the membranous labyrinth. In fact, the whole auditory capsule is growing backwards.

The *cranial* or *occipital* rib, *i.e.*, the costal element corresponding to the occipital arch, is now present. Histogenesis in this structure proceeds from the free to the articular end. The head of the rib is situated slightly in front of the base of the occipital arch in *Lepidosiren* (fig. 14), slightly behind it in *Protopterus* (fig. 15). No other ribs are present yet, but these, when formed, are very much smaller than the occipital ribs.

The hinder ends of the Balkenplatten now approach much more nearly the notochord than in the stage 31, and are only narrowly separated from the occipital plates. The parachordal or basilar plate formed by the fusion of those cartilages strikingly resembles that of the Urodeles. In *Siredon* (Stöhr)* the first part of the skull rudiment to appear are the trabeculæ. Next the Balkenplatten develop, and quickly fuse with the hind ends of the trabeculæ. Next the occipital arch makes its appearance, then the occipital plates grow forwards from their bases and fuse with the Balkenplatten. The attachment of the auditory capsules to the Balkenplatten is by means of a mesotic cartilage. The chief differences between the development of *Siredon* and *Lepidosiren* or *Protopterus* are—

1. The Balkenplatten in the latter, though they appear later than the trabeculæ, appear to chondrify in continuity with them.

2. They are widely separated from the notochord at first.

3. The mesotic cartilage is not a separate structure, in this point agreeing with the majority of Vertebrates (Gaupp). The resemblance to the Urodeles is still greater in *Ceratodus* (Sewertzoff).

The Balkenplatten, trabeculæ, and auditory capsules form completely continuous structures (fig. 8). There is no foramen ovale in the floor of the auditory capsule. The side wall of the auditory capsule is continued for a short distance anteriorly as the external wall of the posterior end of the Gasserian recess. The floor of this recess has become greatly widened by the further development of the horizontal shelf shown in figs. 7 and 13. The postero-external angle of this shelf has fused with the *processus oticus* of the quadrate; this is continued backward to the auditory capsule, or rather to

* *Zeitschr. für wiss. Zool.*, 1880.

the posterior wall of the Gasserian recess, and completes the outer boundary of the hyoideo-mandibular foramen. Internal to this the trabecula is perforated by a small foramen for the superior palatine branch of the seventh nerve (fig. 8, vii. sup. pal.). In front of the Gasserian recess the trabeculæ are raised into the orbito-temporal processes. From the outer side of this is growing back a curved cartilaginous lamina forming the outer wall of the front end of the Gasserian recess. In consequence of the mode of formation of this wall, the ophthalmicus profundus of v. perforates it in an antero-posterior direction. The upper rim of this wall (*tænia marginalis*) is growing back to fuse with a forward growing process of the posterior wall of the Gasserian recess. By their junction the *foramen pro-oticum* (temporal foramen) is enclosed, transmitting the superior and inferior maxillary branches of v., the buccal and superficial ophthalmic branches of vii., and also the ramus communicans between the lateral line systems of vii. and x. (v.^{2}, v.^{3}, vii. lat.); *cf.* figs. 14 and 16.

The orbito-temporal process extends a little further forward than in stage 31, and encloses the foramen for the oculo-motor. This nerve emerges on the outside in the groove formed by v.^{1} after emergence from the Gasserian recess, and joins the latter nerve. Owing to the elongation of the front part of the head, the optic nerve no longer passes out close in front of the orbito-temporal process, but has been pulled forwards (fig. 8). The trabeculæ are continued much further forward than in stage 31. They are produced ventral to the optic nerve, at first as vertical laminæ, further forward becoming horizontal, and pushed upwards by the palatine symphysis. Above this they fuse into a median internasal septum. Behind this the trabeculæ are connected by a sheet of connective tissue which chondrifies later to form the "cartilaginous basis cranii" of Bridge (fig. 9).

The basicranial fontanelle enclosed by the trabeculæ is covered in as to its posterior half by the parasphenoid, which is in this region fused into a median plate. A vacuity is, however, still left underneath the hypophysis. The original paired nature of the parasphenoid is also seen in the two long processes which project backwards under the occipital region. The front end of the fontanelle is open.

The internal carotids enter the skull between the inner edges of the trabeculæ and the parasphenoid, a position which they retain throughout life.

Fig. 14 shows that the palato-pterygoid bone has completed its backward growth, and overlaps the inner surface of the quadrate. Owing to the elongation of the anterior region of the head, this slopes more forward than in stage 31. It is now attached by two processes, the processus oticus and the original one, the processus basalis. It is impossible to speak of a processus ascendens as distinct from the basalis.

The *splenial* is still growing back along the inner surface of Meckel's cartilage, but has not yet begun to curve over on to its outer side.

The sole representative of the opercular apparatus is a free splint of bone (*operculum*) in the position shown.

In fig. 15 is shown a reconstruction from sagittal sections of *Protopterus*, about

stage 36, for comparison with the *Lepidosiren* series. The neural arch *a–b* is present, fused at its dorsal end to the occipital arch, and so enclosing the nerve *a* in a foramen. In another larva of this stage fusion had not taken place, so that *a* comes out through a notch between the two arches, the hinder one (*a–b*) merely forming a protuberance on the base of the occipital arch. My material did not enable me to trace the fate of this apparently vestigial arch.

The occipital arch now touches the auditory capsule, enclosing the jugular foramen. The way in which the junction between the arch and the capsule takes place in *Lepidosiren* has already been described. The stages necessary for showing this process were wanting in *Protopterus*.

The foramen pro-oticum has been completed, and the original single opening has been divided into two by chondrification of a strand of connective tissue separating v.^{2} from v.^{3}, vii. lateralis. In *Lepidosiren* this division never takes place.

The front end of the wall of the Gasserian recess and the orbito-temporal process is produced into a long spine arching backwards towards the auditory capsule.

The *ant-orbital process* is growing out from the dorsal margin of the trabecula. This will be considered more fully later (p. 57).

The dorsal margin of the internasal septum is widening out to form the roof of the nasal capsule.

The *branchial arches* are making their appearance. They develop successively from in front backwards. At this stage the fifth arch has not yet appeared. The first branchial arch at this stage corresponds to the second of WIEDERSHEIM* and BRIDGE. It is behind the first of a series of five clefts. From its relations to the aortic arches, as well as from the fact that there is never a cleft in front of it, this first cleft must be the hyobranchial one—homologous to the one which closes during larval life in *Lepidosiren*, and the first arch at this stage homologous to the first in *Lepidosiren*, while the subsequently appearing cartilage in front of it is no branchial arch. (K. FÜRBRINGER suggests that it is derived from hyoidean rays.)

In the next stage, figured 36+ (fig. 9, Plate II.) the chondrocranium has become further developed. Complete fusion has taken place between the occipital plates and Balkenplatte, and the basilar plate so formed encloses the notochord dorsally and ventrally, except at its front end, which projects freely into the basicranial fontanelle. The free end of the notochord ultimately disappears. The dorsal ends of the occipital arches are growing inwards towards the middle line to form the supra-occipital cartilage.

The front end of the basicranial fontanelle is closed by the "cartilaginous basis cranii." Between this and the internasal septum a vacuity is left.

Shortly behind the level of the eye the ant-orbital process diverges from the trabecula. This process is just recognisable in stage 35. Here we find a short, straight cartilaginous process growing out from the dorsal edge of each trabecula, reaching about

* *Morphol. Studien.* Jena, 1880.

as far forward as the middle of the eye. In the present stage (36+) this process has grown much longer, curving downwards and then forwards into the upper lip, where it fades away into a thick strand of connective tissue supporting the labial fold. It has in fact the relations described and figured by BRIDGE in the adult (figs. 9, 16).

In the interval between stages 34 and 36+, the *nasal capsules* have developed in the following way. From the anterior end of the internasal septum grow out a pair of cartilaginous processes, which grow back to form the ventral rims of the basket-work of the olfactory capsules. These processes are the cornua trabecularum. They fuse behind with an independently formed nodule of cartilage, the *subnasal cartilage* of BRIDGE. Prior to the outgrowth of the trabecular cornua from the front end of the internasal septum, four cartilaginous outgrowths appear from the dorsal edge of this septum on each side. These grow outwards and downwards to fuse with the ventral rims which have been formed by the cornua, and thus the fenestrated olfactory capsules are constituted.

Occupying the fold of mucous membrane in the angle between the middle and posterior palatine tooth plates, and not in any way connected with any other skeletal structure, is the rudiment of BRIDGE's *upper labial cartilage* (shown in fig. 16).

BRIDGE homologises HUXLEY's * anterior upper labial of *Ceratodus* with his (BRIDGE's) subnasal cartilage in *Lepidosiren*. In *Ceratodus* this cartilage is separate from the nasal capsule. Comparison with the adult *Lepidosiren* led BRIDGE to suppose that this independence was secondary, and that the name upper labial was inappropriate, the cartilage really representing a disjointed part of the olfactory capsule. K. FÜRBRINGER was of the same opinion. The independence of this cartilage in the young *Lepidosiren*, however, shows that HUXLEY was in all probability right in his nomenclature.

As regards HUXLEY's posterior upper labials in *Ceratodus*, SEWERTZOFF's discovery that these are in the young *Ceratodus* continuous with the ethmoidal region of the trabecula, seems to establish RÖSE's suggestion (quoted by BRIDGE) that these represent the ant-orbital processes of *Protopterus* and *Lepidosiren*, which have become separated off in *Ceratodus*. (SEWERTZOFF himself does not discuss RÖSE's suggestion.) Hence there is no cartilage in *Ceratodus* corresponding with the posterior upper labial in the Dipneumona (the only labial cartilage allowed by BRIDGE). The condition of the labial cartilages in the Dipnoi is then as follows:—All three genera have anterior upper labials, which in *Ceratodus* remain free throughout life, but in the Dipneumona † fuse with the olfactory capsules during the larval stage. *Protopterus* and *Lepidosiren* alone have posterior upper labials. In *Ceratodus* these are wanting, but the ant-orbital processes get separated from the trabeculæ during development and simulate the posterior upper labials of the other two genera.

* *Proc. Zool. Soc.* Lond. 1876.

† Owing to the larger gaps between the successive stages of *Protopterus* available, I have been unable to prove the original independence of this cartilage in this genus.

Growing out from the end of the internasal septum, slightly ventral to the cornua trabecularum, is the prenasal process, which first appears about this stage.

The opercular apparatus is particularly interesting at this stage. The hyoid arch is sheathed in bone except at the symphysis and on the posterior face of the proximal (vertical) portion, where the cartilage remains exposed throughout life. Intimately attached to it at this point—in a stage earlier there is no definite line of demarcation between the two—is a narrow plate of connective tissue which runs backward into the opercular fold. In this plate (some distance from the hyoid) chondrification is taking place—the rudiment of the *interopercular cartilage* found on the inner surface of the bone in the adult (Bridge). The interopercular bone has already appeared. On the inner side of the posterior end of the *opercular bone* (which was already present in stage 34) there is another patch of connective tissue in which chondrification is proceeding—the rudiment of the cartilaginous nodule found in this place in the adult. Both these strands of connective tissue fade away behind into the general connective tissue of the opercular fold. To finish the account of these structures we may take them up again in stage 38, fig. 16, in which they are practically in the adult condition. The operculum consists of a nearly horizontal strip of bone attached in front by connective tissue to the lower edge of the squamosal, and ending freely behind. Here, to its inner side, is attached the cartilaginous nodule mentioned above. The interopercular cartilage is a long rod attached to the angle of the hyoid by a pad of connective tissue. It is invested by bone (the interoperculum) on its outer side. This bone, though it does not appear so soon as the operculum, nevertheless like it is laid down before the cartilage underlying it.

The facts of the development of these parts are in favour of Huxley's * suggestion for *Ceratodus* and Bridge's for the Dipneumona, that the cartilages in connection with the operculum and interoperculum represent vestigial hyoidean branchiostegal rays. The stoutness of the interopercular ray is comparable to the great development of the hyomandibular ray in *Polypterus*, which also persists as a nodule of cartilage on the inner side of the opercular bone in this form (Budgett).†

All the bones have by now appeared. The *parasphenoid* now fills up the whole of the basicranial fontanelle, and has lost all trace of its paired origin. The *palato-pterygoid* had already attained its characteristic features in stage 34 (figs. 8 and 14). The symphysis, however, is now more massive and pushes up the anterior ends of the trabeculæ at a sharper angle than before (*cf.* figs. 2 and 4).

The *splenial* has completed its growth backwards, and instead of being confined to the inner side of Meckel's cartilage, now arches over the top and partly covers it over on the outside, leaving, however, a strip of cartilage exposed along the ventral outer edge of the mandible (fig. 16). At its posterior end this strip is overlaid by a small splint of bone, the *angular*.

We left the *dermal ectethmoid* as a short rod of bone on the end of the ascending

* *Proc. Zool. Soc.* Lond., 1876.

† *Trans. Zool. Soc.* Lond., vol. xvi. part vii., 1902.

process of the palato-pterygoid. In process of development the bone grows backward in the fascia of the temporal muscle, keeping pace with the posterior extension of the line of origin of this muscle. At first the muscle is circular in horizontal section,* but as development proceeds the circle becomes more and more pulled out antero-posteriorly as the muscle spreads backwards, to reach ultimately nearly to the hind end of the auditory capsule. The posterior end of the dermal ectethmoid keeps a constant distance in front of the posterior limit of the muscle. This relation to the muscle in development is in favour of WIEDERSHEIM's identification of this as a tendon bone. The anterior end of the bone never has the intimate relations with the nasal capsule described by BRIDGE for its homologue in *Ceratodus*, being from the first separated from it by the processus ascendens of the palato-pterygoid.

The *dermal ethmoid* has appeared, investing the cartilaginous roof of the nasal capsules.

The *squamosal* is applied to the outer surface of the quadrate. The internal mandibular branch of vii. runs between the cartilage and the bone.

The *fronto-parietal* is the last bone to appear. In stage 36 + the only calcification is in the descending processes which overlie the upper part of the quadrate cartilage. At this stage, therefore, the bone is paired. The connective tissue connecting the two first-formed plates becomes ossified by the meeting of these plates in stage 37. There is, therefore, nothing in the development of this bone which supports K. FÜRBRINGER's scheme for homologising it with the sclero-parietal of *Ceratodus*. The fronto-parietal was not present in the oldest *Protopterus* larva (stage 36).

All the above-mentioned bones are membrane bones. The bone forming the sheath round the hyoid arch, round the occipital arch (the pleuro-occipital bones), and round the occipital rib is, however, deposited in the perichondrium, in direct contact with the cartilage. These are therefore ectochondral bones. Endochondral ossification, as is well known, does not take place.

In stage 38, fig. 16, the skull has nearly reached its adult proportions. The chief advance made by the chondrocranium over stage 36 + is the meeting in middle line of the occipital arches to form the supra-occipital cartilage. This cartilage is produced posteriorly in the middle line beneath the fronto-parietal, and in front extends a short distance along the dorsal edges of the auditory capsules. From the outer edge of the otic process of the quadrate a shelf of cartilage is growing out, underlying the squamosal bone. Underneath the foramen pro-oticum this forms a cartilaginous loop enclosing † "Pinkus's organ." (This loop is present in stage 36 +, but not visible in a dorsal view.)

Fig. 16 shows the nodules of cartilage which have been supposed to represent *lower labials*. Both these cartilages develop independently from Meckel's cartilage, just as K. FÜRBRINGER found in a young *Protopterus*. The anterior nodule develops before the posterior one, and about this stage becomes connected with Meckel's cartilage. The posterior one remains separate throughout life.

* *Cf.* fig. 10.

† AGAR, *Anat. Anz.*, Bd. xxviii., 1906.

FÜRBRINGER rejected the supposition that they are lower labials on the ground that they have no representatives in *Ceratodus*, and suggests the name *paramandibulars* for them.

The fronto-parietal bone at this stage (fig. 16) shows a distinctly intermediate form between that of the adults of *Lepidosiren* and *Protopterus*. A very large proportion of the auditory capsule is left exposed, owing to the slight ventral extension of the bone, while anteriorly the lateral plate, *i.e.* that part of the bone which forms the side wall of the cranium above the trabecula, leaves a considerable fenestra, closed by membrane, between it and the ascending process of the palato-pterygoid. The optic nerve leaves the skull through this foramen.

It will be noticed that the foramen for the oculo-motor is placed in a slightly different position to that figured by BRIDGE. The course of this nerve through the orbito-temporal process, and its application to the ophthalmicus profundus branch of the trigeminal, has already been mentioned; the two nerves run close together in a groove between the cartilage and the inner surface of the bone, emerging together under the edge of the latter as shown.

As regards the development of the patch of cartilage on the anterior surface of the distal end of the hyoid, supposed by BRIDGE to represent a vestigial hyoidean ray, there is not much to say. It appears very late, not being present even at stage 38 (about three months after hatching). I found it in sections of a *Lepidosiren* of about eighteen months, and also in a *Protopterus* of 7·5 cm. It lies, as BRIDGE describes, external to the osseous sheath.

Lack of the necessary stages has prevented me from going into the question of the patch of cartilage found on the anterior surface of the occipital rib in *Protopterus*, and to which various homologies have been ascribed. It does not appear till after stage 36.

In the change from stage 38 to the adult, there is no absorption or replacement of cartilage, except in the pleuro-occipital region in *Lepidosiren*. The sheath of bone round each occipital arch increases in thickness, and finally forms a solid bone with a deep notch in its dorsal end into which the supra-occipital cartilage extends.* The bone, at first circular in section like the other neural arches, becomes pulled out in an antero-posterior direction, remaining constricted in the middle, however, by the notches for the exit of the occipital nerves in front, and of the spino-occipital *a* behind.

Otherwise the chondrocranium of the adult is in both genera more complete than in the young form. In *Lepidosiren*, in the auditory region the cartilage spreads further up under the fronto-parietal, without, however, meeting in the middle line. The shelf of cartilage under the squamosal increases in width and thickness. The backwardly projecting styliform process of the mesethmoid cartilage is not, as BRIDGE suggests, a remainder of the more extensive cartilaginous cranial roof of the young. The mesethmoid itself first appears in stage 36+ as a backward extension of the internasal septum (*cf.* figs. 14 and 16), and thence increases to the adult size.

* The cartilage is not absorbed, but squeezed out at each end of the bony sheath as this thickens.

In a *Protopterus* of 7·5 cm. long the auditory capsules are connected dorsally from about the middle of their length backward. The anterior part of the roof is separated from the supra-occipital cartilage by a region of much thinner cartilage, probably indicating the formation of a *tectum synoticum* distinct from the supra-occipital cartilage. The spine arising from the anterior end of the Gasserian recess in *Protopterus* of about stage 36 (fig. 15) is the forerunner of a great increase in the dorsal extent of the wall of the recess. In the 7·5 cm. specimen the space between this and the auditory capsule has become filled up with cartilage.

Another example of the increase in the bulk of cartilage which takes place between the stage 36 and the 7·5 cm. *Protopterus* is the fact that whereas in the former, as in all stages of *Lepidosiren*, the external carotid enters the skull by the hyoideo-mandibular foramen and runs over the floor of the Gasserian recess to the foramen pro-oticum where it issues to the exterior, in the latter the artery is embedded in the floor of the recess, instead of coursing freely through its cavity.

Thus it appears that ontogeny gives no support to the prevailing view that the complete chondrocranium of *Ceratodus* exhibits a more primitive and ancestral condition than that of the Dipneumona, and that of the latter, *Protopterus* retains its skull in a more primitive condition than *Lepidosiren*.* In many respects the adult *Lepidosiren* is in the same condition as a larval *Protopterus*. For instance, the following points are common to both: the absence of a tectum synoticum, the small extent of the mesethmoid cartilage and its styloid process (these are of much greater extent in the adult *Protopterus* than in *Lepidosiren*), the course of the external carotid through the cavity of the cranium between the hyoideo-mandibular and pro-otic foramina. Also in the very young *Protopterus* the foramen pro-oticum is undivided, but it must be noted that the division takes place at an early stage. None of these apparently more primitive characters are, so far as we can learn from ontogeny, coenogenetic. On the other hand, as regards the visceral arches and the neural arch *a–b*, *Ceratodus* is in the most primitive condition.

Summary.

The extreme anterior end of the notochord degenerates, and is replaced by forward growth of the definitive notochord.

The trabeculæ are the first parts of the skull basis to appear.

The "Balkenplatten" appear subsequently to the trabeculæ, but in continuity with them. There is no distinct mesotic cartilage.

The occipital arch has the form of a neural arch. The occipital plates grow forward

* It should, however, be mentioned that Wiedersheim (*loc. cit.*) found in a young *Protopterus* that the mesethmoid filled up the whole space between the ascending processes of the palato-pterygoids, *i.e.* was more extensive than in the adult. In my 7·5 cm. specimen the mesethmoid had the adult form of a narrow, backwardly projecting spine of the internasal septum.

from their bases. The arch is between the third and fourth metotic myomeres (Z and A).

The quadrate is from the first continuous with the trabecula. There is no hyomandibular.

There appears to be a vestige of a palato-pterygoid cartilage.

The parasphenoid develops from paired rudiments, separated by the hypophysis.

The internasal septum is formed by the fusion of the anterior ends of the trabeculæ. The nasal capsule is formed by outgrowths from this septum, with fusion with the anterior upper labial cartilage.

There are two upper labial cartilages, anterior and posterior.

The cartilage in connection with the interoperculum appears to be a hyoidean ray (Huxley, Bridge).

The dermal ectethmoid develops in connection with the temporal muscle.

The cartilaginous cranial roof in the auditory and occipital region is confined to the supra-occipital cartilage in *Lepidosiren*, while there is in addition a tectum synoticum in *Protopterus*.

In the successive stages from the embryo to the adult the chondrocranium shows a steady relative increase in completeness.

EXPLANATION OF THE PLATES.

Plate I.

Camera drawings of median sagittal sections illustrating the development of the front end of the notochord in *Lepidosiren*.

Fig. 1. Stage 25. Zeiss D. 2oc.
Fig. 2. Stage 26. Zeiss A. 4oc.
Fig. 3. Stage 31. Zeiss A. 4oc.
Fig. 4. Stage *circ.* 32. Zeiss A. 4oc.
Fig. 5. Stage 38. Zeiss A. 4oc.
Fig. 6. Stage – 35. 3 mm. imm. 2oc.

Plate II.

Fig. 7. *Protopterus*, stage *circ.* 31. Reconstruction (by Graham Kerr's method) from horizontal sections.

Fig. 8. *Lepidosiren*, stage 34. Reconstruction from horizontal sections. X, Y, Z, etc., are the myomeres corresponding to the nerves *x*, *y*, *z*, etc. The bones are shown in outline on the transparency.

Fig. 9. *Lepidosiren*, stage 36+. Reconstruction from horizontal sections.

Fig. 10. Horizontal section through the ventral end of the quadrate of *Protopterus*, stage *circ.* 31, to show the connective tissue strand representing the vestige of the palato-pterygoid cartilage. Zeiss A. 4oc. Camera lucida.

Fig. 11. Similar section (*Protopterus*), stage 34. Zeiss A. 4oc. Camera lucida.

Fig. 12. Transverse section through the thalamencephalon in *Lepidosiren* to show the back-growth of the palato-pterygoid bone along the inner side of the connective tissue strand. Stage 34. Slightly higher magnification than figs. 10 and 11. Camera lucida.

Plate III.

Fig. 13. *Protopterus*, stage *circ.* 31. The same reconstruction as shown in fig. 7, seen from the side.

Fig. 14. *Lepidosiren*, stage 34. Reconstruction from sagittal sections. The bones are shown in outline.

Fig. 15. *Protopterus*, stage *circ.* 36. Reconstruction from sagittal sections. The bones are shown in outline.

Fig. 16. *Lepidosiren*, stage 38. Reconstruction from sagittal sections. The bones are shown in outline.

ABBREVIATIONS USED IN THE MAIN FIGURES.

a.g.r., wall of anterior end of Gasserian recess.
a.n., anterior naris.
a o.p., ant-orbital process.
art., artery given off from aortic root.
aud. caps., auditory capsule.
Balk., Balkenplatte.
bas. pl., basilar plate.
bcr. f., basicranial fontanelle.
br. 1–5, branchial arches 1–5.
c.b.c., cartilaginous basis cranii.
cor. pr., coronoid process.
c.t., connective tissue strand representing vestige of palato-pterygoid cartilage.
fl., floor of Gasserian recess.
G.r., Gasserian recess.
h., hyoid.
h.br., floor of hind-brain.
hd., outline of head.
hph., hypophysis.
hypo., hypoblast.
i.c., internal carotid.
inf., infundibulum.
i.op.c., interopercular cartilage.
int.s., internasal septum.
j.f., jugular foramen.
m., mass of tissue concentrated by advancing tip of notochord.
Meck., Meckel's cartilage.
mes., mesethmoid.
n., nucleus.
n.a., neural arch.
n.a.v., vestigial neural arch.
nch., notochord.
occ. arch., occipital arch.
occ. pl., occipital plate.
o.r., occipital rib.
ol., olfactory organ.
op.c., opercular cartilage.
o.t.p., orbito-temporal process.
p., parasphenoid.
par., paramandibular cartilages.
p.g., pectoral girdle.
p.g.r., wall of posterior end of Gasserian recess.
p.o., loop of cartilage round "Pinkus' organ."
p.n., posterior naris.
prn., prenasal process.
pr.b., processus basalis.
pr.ot., processus oticus.
p.-pt., palato-pterygoid bone.
pr.s., prochondral strand connecting auditory capsule with occipital arch.
p.s., primary sheath of notochord.
quad., quadrate.
r.n.c., roof of nasal capsule.
rud., rudiment of palatine tooth.
sh., shelf of cartilage underlying squamosal.
sp., spine.
s.n.c., subnasal cartilage.
s.s., secondary sheath of notochord.
sup. oc., supra-occipital cartilage.
symph., symphysial plate.
thal., thalamencephalon.
tr., trabecula.
trab., bony trabeculæ of palatine tooth.
tr. ant., anterior extension of trabecula.
tr.c., trabecular cornu.
t.m., temporal muscle.
t. marg., tænia marginalis.
u.l.c., upper labial cartilage.
vac., vacuity over highest point of palatine symphysis.
y., yolk granule.
I, olfactory nerve.
II, optic nerve.
III, oculo-motor.
V^1, ophthalmicus profundus branch of trigeminal.
V^2, superior maxillary branch of trigeminal.
V^3, inferior maxillary branch of trigeminal.
VII *hyo.*, hyoideo-mandibular branch of facial.
VII *lat.*, buccal and superficial ophthalmic branches of the facial, and ramus communicans between VII and X.
VII *sup. pal.*, superior palatine branch of facial.
IX, glossopharyngeal.
X, vagus.

ABBREVIATIONS USED IN THE TRANSPARENCIES.

ang., angular.
d. ect., dermal ectethmoid.
d. eth., dermal ethmoid.
fen., fenestra.
f.p., fronto-parietal.
int., interoperculum.
op., operculum.
p.-pt., palato-pterygoid bone.
pal. t.p., palatine tooth-plates.
par., parasphenoid.
pl. occ., pleuro-occipital.
pr. as., ascending process of palato-pterygoid.
spl., splenial.
sq., squamosal.
vac., vacuity under hypophysis.
vom. t., vomerine tooth.

PLATE I.

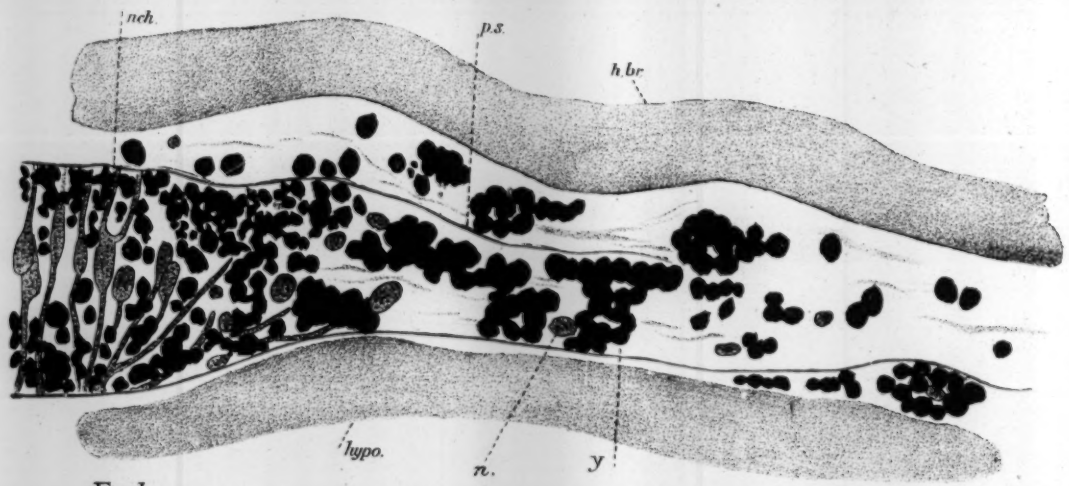


Fig I.

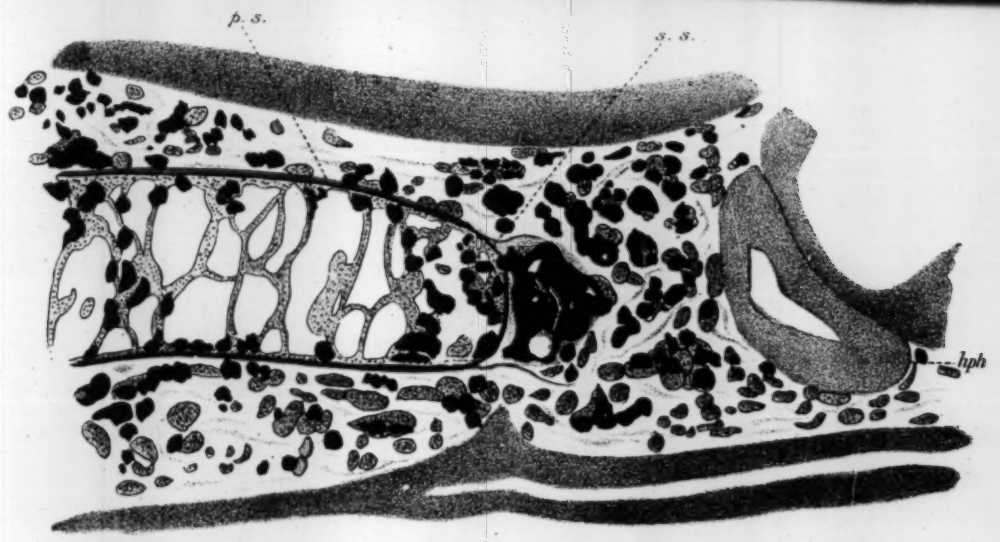


Fig. 4.

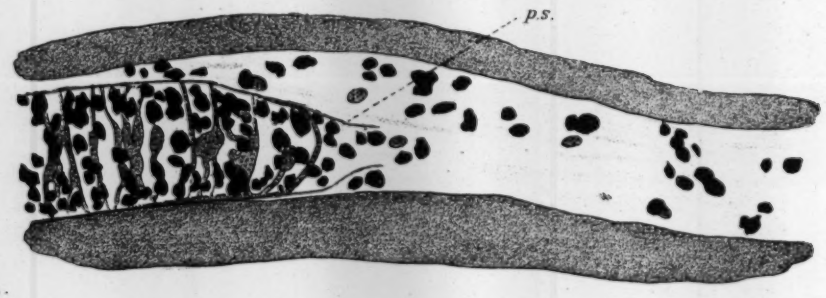
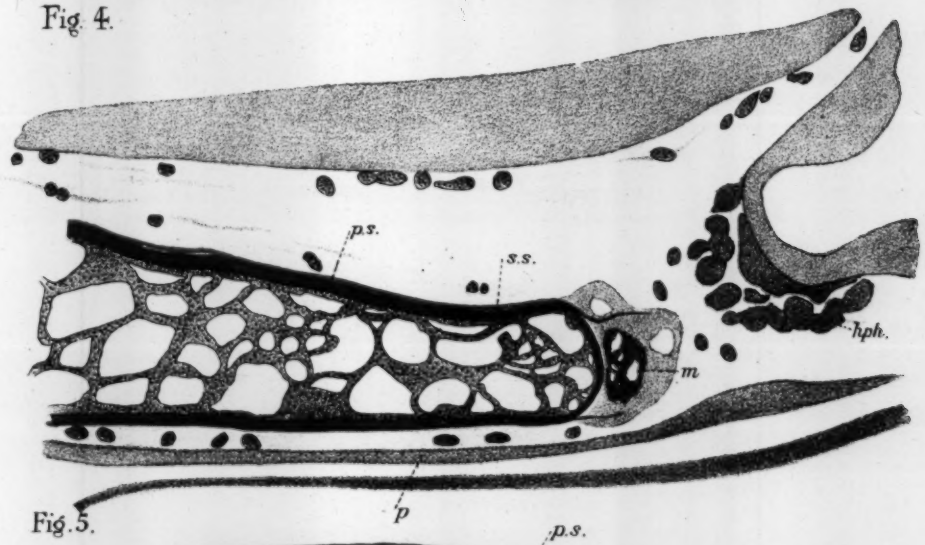


Fig. 2.



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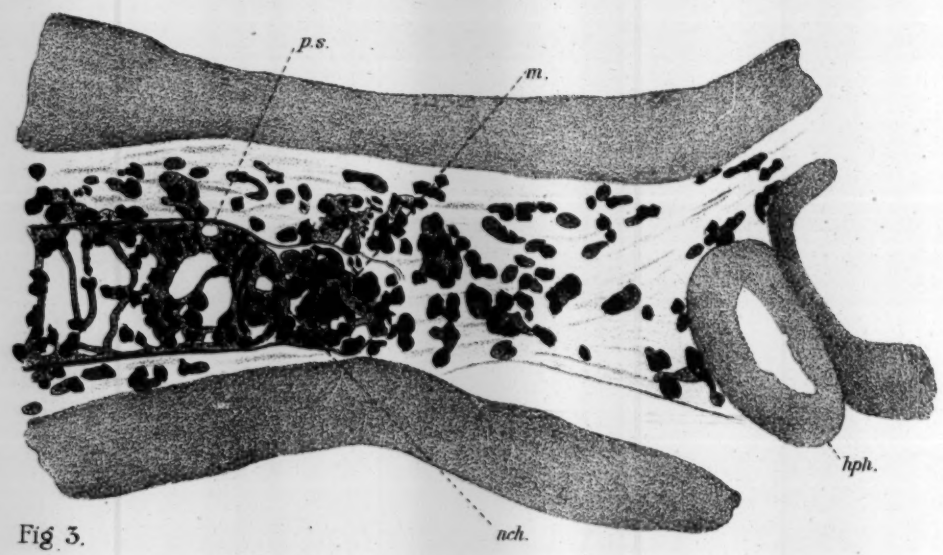

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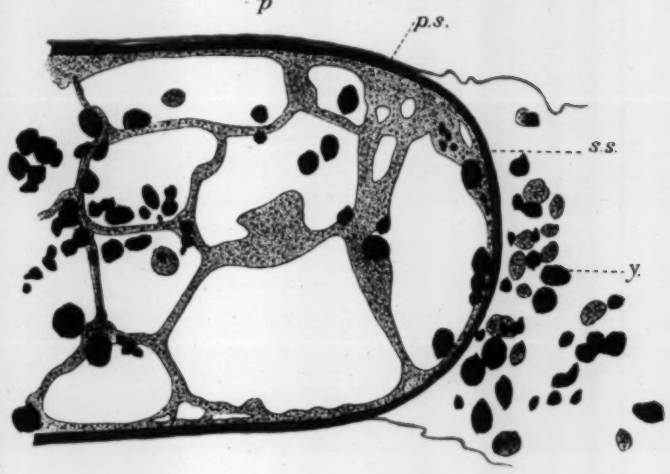

Fig. 6.

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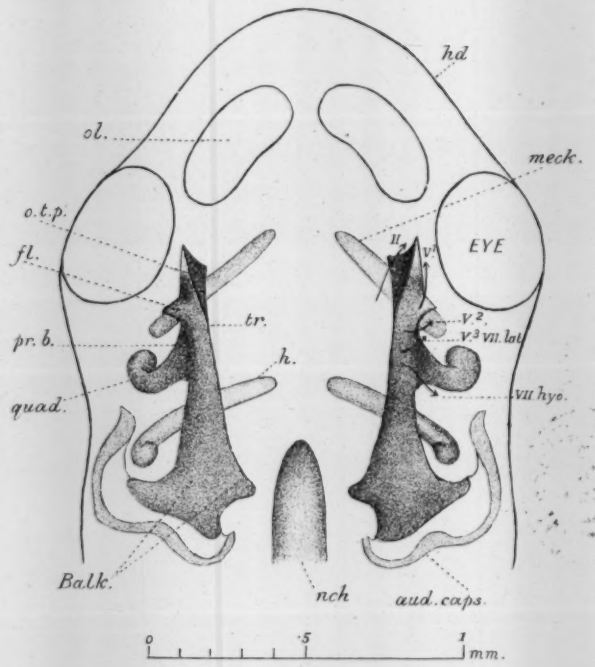
LEPIDOSIREN.

PLATE II



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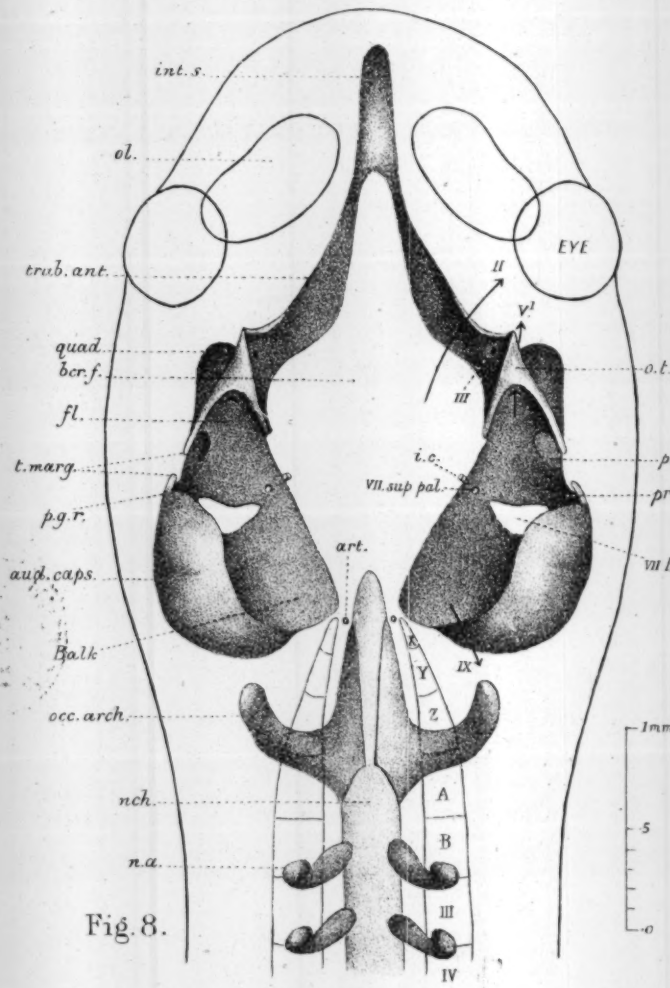
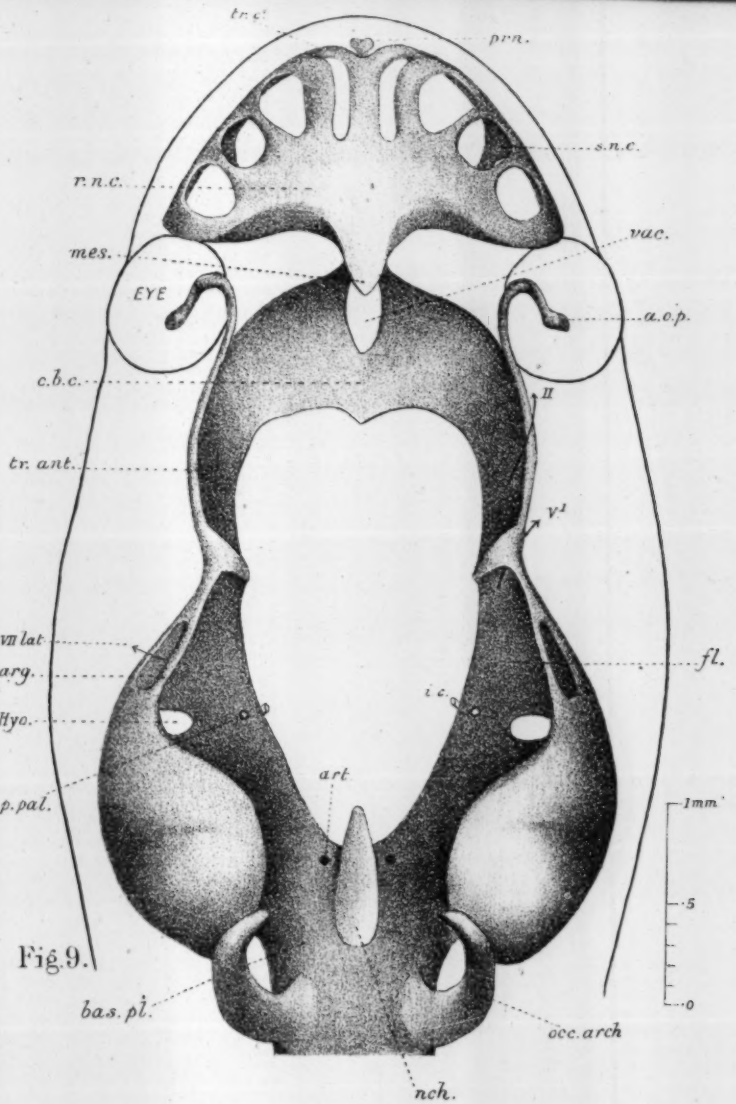


Fig. 8.



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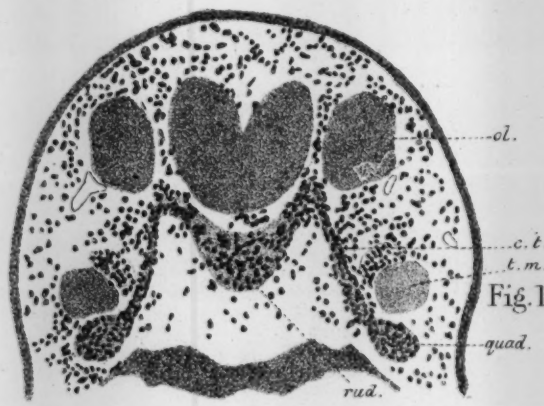

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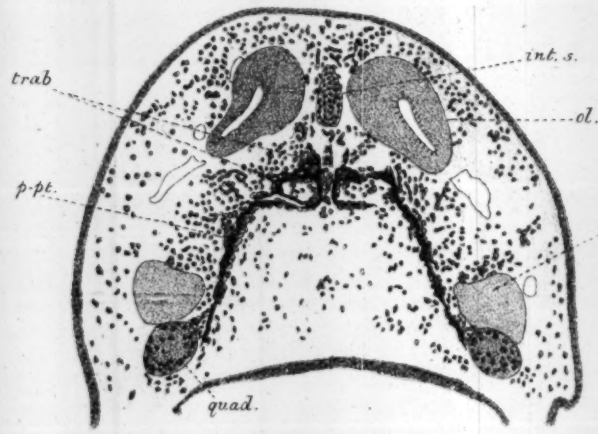

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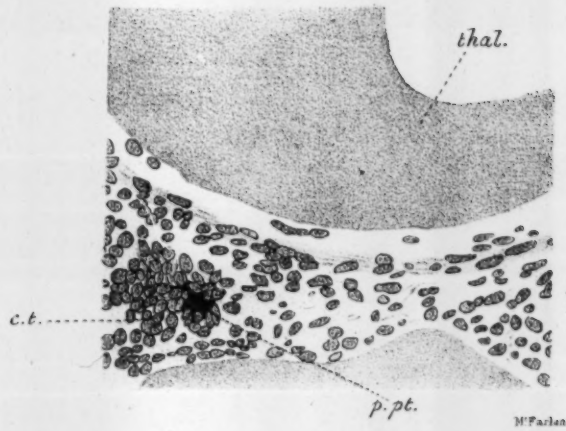

Fig. 12.

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M'Farlane & Erskine Lith. Edin.

Fig. 7, PROTOPTERUS. Fig. 8, LEPIDOSIREN. Fig. 9, LEPIDOSIREN.

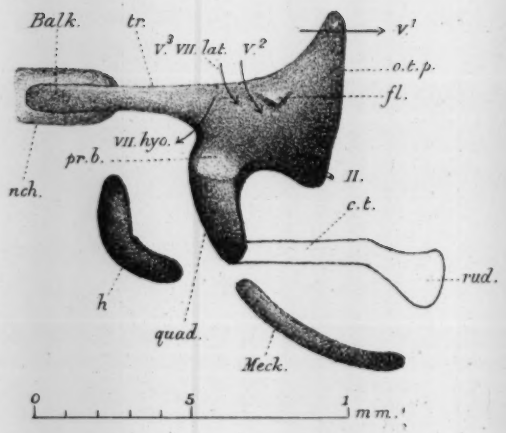

Fig. 13.

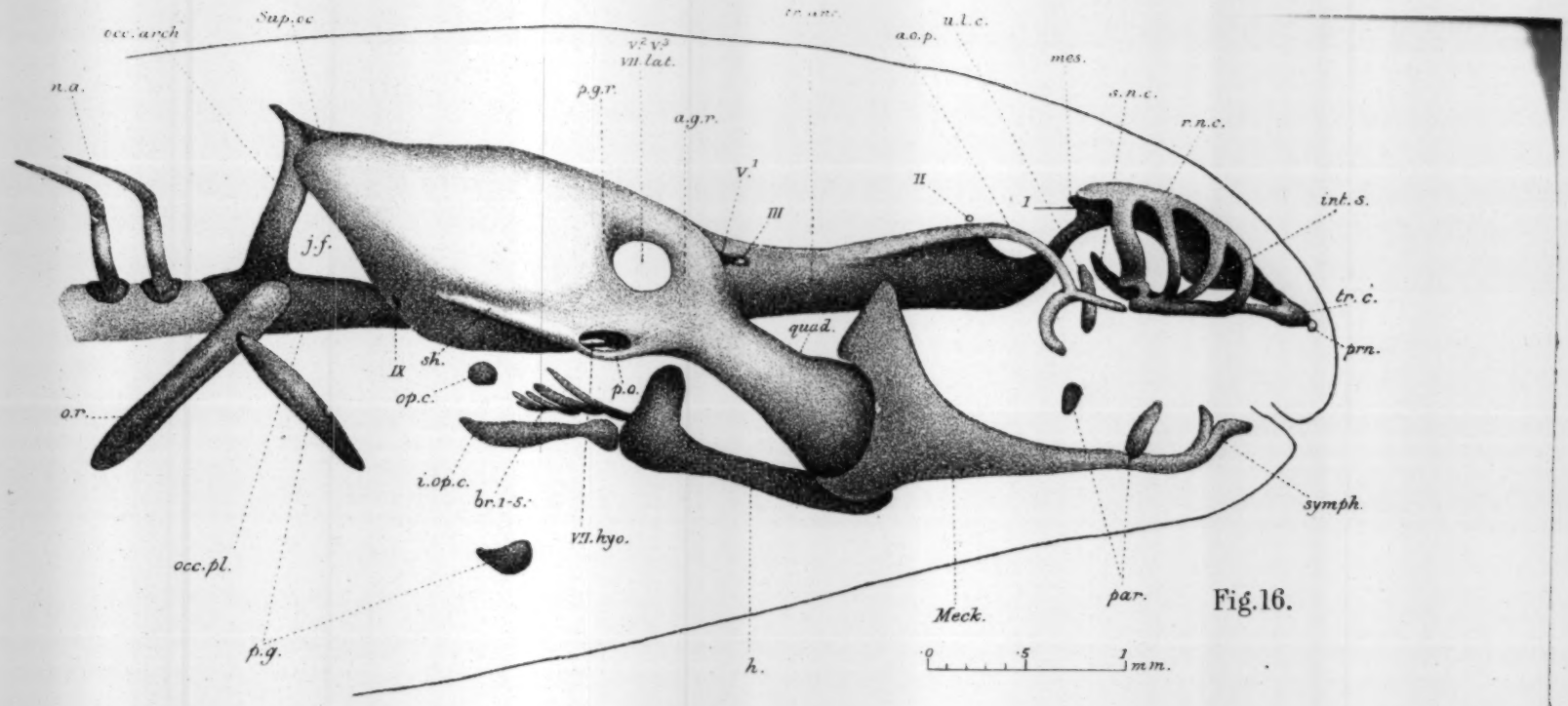

Fig.16.

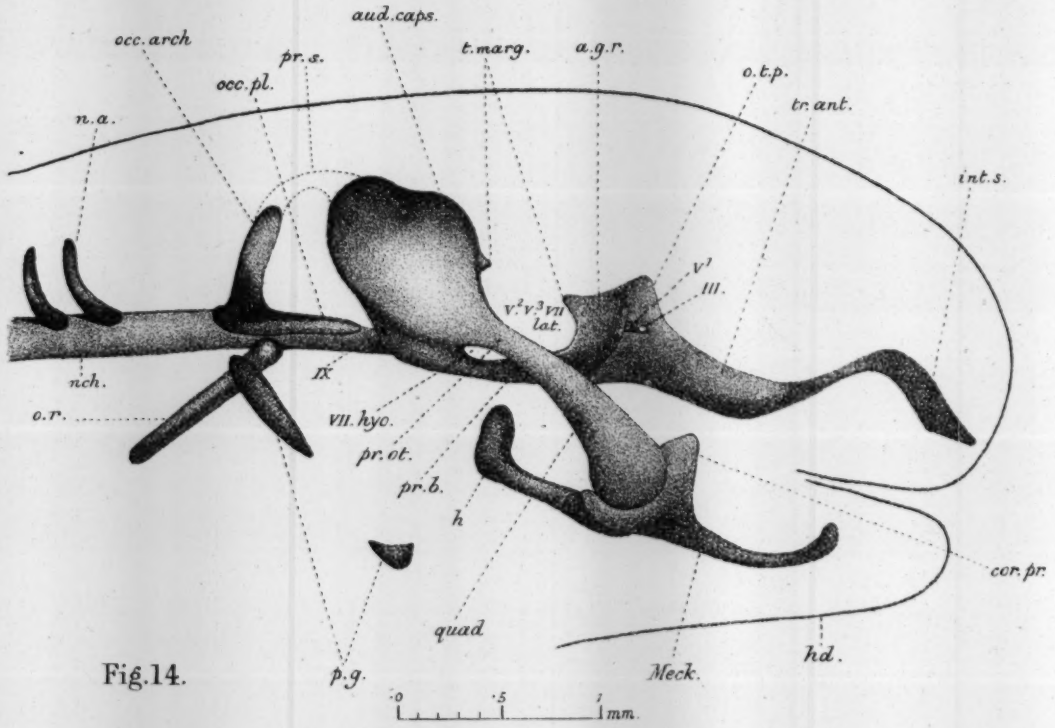

Fig.14.

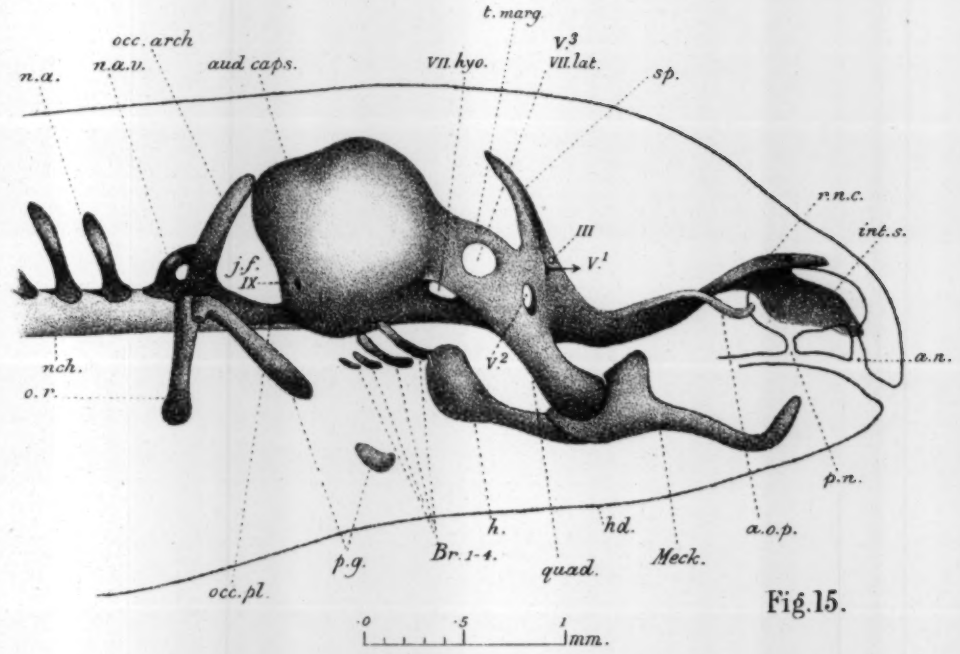

Fig.15.

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Fig. 13, PROTOPTERUS. Fig. 14, LEPIDOSIREN. Fig. 15, PROTOPTERUS. Fig. 16, LEPIDOSIREN.

IV.—Observations on the Normal Temperature of the Monkey and its Diurnal Variation, and on the Effect of Changes in the Daily Routine on this Variation.

By **Sutherland Simpson**, M.D., D.Sc., and **J. J. Galbraith**, M.D. (From the Physiological Laboratory of Edinburgh University.) *Communicated by* Professor E. A. Schäfer, F.R.S. (With a Plate.)

(MS. received October 25, 1905. Read November 20, 1905. Issued separately January 23, 1906.)

PART I.

Introduction.

The observations recorded in the following pages were begun upwards of four years ago. In the course of an investigation into the anatomy and physiology of the central nervous system of the monkey, it was deemed necessary, amongst other things, to note whether the lesions established had influenced the temperature of the affected limbs. On consulting the chapter on "Animal Heat" by Pembrey in Schäfer's *Text-book of Physiology*, and Richet's article "Chaleur," in the *Dictionnaire de Physiologie* to find what the normal temperature of the monkey was, it was discovered that very few observations on the temperature of this animal had been made. Considering the high position which the monkey occupies in the animal scale, it seemed to us that this was an omission which we might with advantage do something to remedy; we decided therefore to avail ourselves of the material at our disposal, and to record the temperature of such healthy monkeys as should come into the laboratory from time to time.

Methods Adopted in taking the Temperature.

Readings were taken from the rectum and axilla, and in some cases from the groin as well. An accurate one-half-minute Kew-certificated clinical thermometer was employed. It was held in position $2\frac{1}{2}$ minutes, and in the rectum was always introduced to the same depth (from 5 to 6 centimetres) in each case, well within the internal sphincter, in order to obtain comparable readings. In the axilla the bulb of the thermometer was pushed up as far as possible into the apex, the stem lying against and parallel with the long axis of the upper arm, which was then held gently against the side of the animal, thus converting the axilla practically into a closed cavity. When the groin temperature was taken the proceeding was similar, but it was found to be very inconvenient as compared with the axilla, and it was given up.

The animals—ordinary macaque monkeys (*rhæsus* and *sinicus*)—were for the most part young adults, but a considerable number were probably not full grown. The sources from which they came could not be determined with certainty. They were

kept in a large wire cage, 4 metres long, 5 high, and 1½ wide, and were allowed to move about freely within. The room was well ventilated, and the temperature ranged between 20° C. and 27° C. (70° F. and 80° F.). It was soon found that a comparatively slight amount of muscular exercise was sufficient to cause a very appreciable rise in the temperature, and to eliminate this important source of error, only quiet animals were used which would submit to the operation without struggling. Half-an-hour before a reading was to be taken they were captured and each placed in a small cage by itself. In many cases they were so tame that the temperature could be taken by a single observer without any help, but when necessary they were held on the lap of an assistant, not on account of their struggling, but to prevent the thermometer being broken by any sudden, unexpected movement At first most of the observations were made between 5 and 6 p.m., a few between 9 and 10 a.m. and 2 and 3 p.m. respectively, but later, as will be shown, they were made continuously at short intervals throughout the twenty-four hours.

Results.

Our results are given in tabular form as they were recorded, and from these a series of averages have been obtained from which some definite conclusions have been arrived at. This method of presenting it will show how the subject developed in our hands, and how we were led to make it a much more elaborate and laborious investigation than we had originally intended. The readings are recorded in degrees centigrade.

MONKEY I. (*Macacus rhœsus*).
♂ Young Adult.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 8th, 5.30 p.m.	38·6	38·7	38·4	38·4	38·4	23·3
,, 9th, 2 ,,	38·0	38·1	.	.	38·0	23·3
,, 10th, 5 ,,	39·2	39·2	38·9	.	38·9	20·6
,, 11th, 5.30 ,,	38·8	38·6	38·5	38·4	38·6	22·2
,, 12th, 10 a.m.	.	.	.	.	38·1	24·4
,, ,, 5 p.m.	38·9	39·0	38·7	38·9	38·8	22·8
,, 13th, 5 ,,	38·1	38·3	38·1	38·2	38·2	22·5
,, 14th, 9.30 a.m.	.	.	.	.	37·9	21·7
,, 15th, 9.30 ,,	.	.	.	.	37·7	25·0
,, ,, 5.30 p.m.	37·9	37·8	37·9	37·7	38·0	23·9
,, 16th, 2 ,,	38·0	38·1	37·8	37·8	37·9	25·0
,, 21st, 5 ,,	38·8	38·9	38·7	38·5	38·7	26·4
,, 26th, 2.30 ,,	38·8	38·2	37·9	38·0	37·9	26·1

	Mean.	Max.	Min.	Range.
20 Observations—Axilla .	38·5	39·2	37·8	1·4
17 ,, Groin .	38·3	38·9	37·7	1·2
13 ,, Rectum .	38·2	38·9	37·7	1·2
13 ,, Room .	23·7	26·4	20·6	5·8

MONKEY II. (*M. sinicus*).
♀ Young Adult.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 8th, 5.30 p.m.	39·4	39·4	39·3	39·3	39·3	23·3
,, 9th, 2 ,,	38·7	38·6	38·4	38·4	38·5	23·8
,, 10th, 5.30 ,,	38·9	39·1	38·8	38·8	38·8	20·6
,, 11th, 5.30 ,,	39·2	39·3	38·8	38·9	39·1	22·2
,, 12th, 10 a.m.	38·4	38·5	38·3	38·2	38·2	24·4
,, 13th, 5 p.m.	38·4	38·5	.	.	38·6	22·5
,, 14th, 9.30 a.m.	.	.	.	.	38·0	21·7
,, 15th, 9.30 ,,	38·3	38·4	38·1	38·2	38·1	25·0
,, ,, 5.30 p.m.	38·6	38·8	38·4	38·6	38·7	23·9
,, 16th, 2 ,,	38·4	38·5	38·3	38·4	38·4	25·0

	Mean.	Max.	Min.	Range.
18 Observations—Axilla .	38·7	39·4	38·3	1·1
16 ,, Groin .	38·6	39·3	38·1	1·2
10 ,, Rectum .	38·6	39·3	38·0	1·3
10 ,, Room .	23·2	25·0	20·6	4·4

MONKEY III. (*M. sinicus*). ♀ Adult.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 7th, 9.30 a.m.	37·8	37·9	37·8	37·7	38·1	24·4
,, ,, 5.30 p.m.	37·3	37·4	37·7	37·6	37·8	25·0
,, 8th, 5.30 ,,	38·1	37·9	37·7	37·8	37·8	23·3
,, 9th, 2 ,,	38·4	38·6	38·3	38·4	38·4	23·3
,, 10th, 5.30 ,,	39·1	38·9	38·8	38·7	38·8	20·6
,, 11th, 5.30 ,,	38·2	38·3	38·0	38·1	38·2	22·2
,, 12th, 10 a.m.	38·1	38·2	37·8	37·9	37·9	24·4
,, ,, 5 p.m.	38·3	38·4	38·2	38·2	38·3	22·8
,, 13th, 5.30 ,,	38·3	38·4	38·2	38·1	38·2	22·5
,, 14th, 9.30 a.m.	.		.	.	37·4	21·7
,, 15th, 9.30 ,,	.	.	.	.	39·4	25·0
,, ,, 5.30 p.m.	38·9	39·1	38·9	38·9	39·1	23·9
,, 16th, 2 ,,	38·4	38·3	38·3	38·2	38·3	25·0
,, 21st, 5.30 ,,	38·9	39·1	38·9	38·8	38·8	26·4

	Mean.	Max.	Min.	Range.
24 Observations—Axilla .	38·3	39·1	37·3	1·8
24 ,, Groin .	38·2	38·9	37·6	1·3
14 ,, Rectum .	38·2	39·4	37·4	2·0
14 ,, Room .	23·6	26·4	20·6	5·8

MONKEY IV. (*M. rhæsus*). ♀ Adult.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 21st, 5.30 p.m.	39·1	39·1	38·9	39·0	39·1	26·4
,, 22nd, 9.30 a.m.	38·8	.	.	.	38·7	26·1
,, ,, 5 p.m.	39·0	39·1	.	.	39·0	25·0
,, 26th, 5 ,,	.	.	.	.	38·9	23·9
,, 27th, 4 ,,	.	.	.	.	38·8	25·0
,, 28th, 5 ,,	.	.	.	.	38·9	25·6
Mar. 4th, 5.30 ,,	39·0	39·1	.	.	38·8	24·6

	Mean.	Max.	Min.	Range.
7 Observations—Axilla .	38·9	39·1	38·8	0·3
2 ,, Groin .	38·9	.	.	.
7 ,, Rectum .	38·9	39·1	38·7	0·4
7 ,, Room .	25·2	26·4	23·9	2·5

MONKEY V. (*M. rhæsus*). ♀ Immature.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 22nd, 9.30 a.m.	.	.	.	.	38·4	26·1
,, ,, 2.30 p.m.	.	.	.	.	38·6	25·3
,, 23rd, 2.30 ,,	38·9	38·9	.	.	38·8	25·3
,, 25th, 5.30 ,,	39·1	39·3	38·8	38·8	38·9	25·6
,, 26th, 5.30 ,,	.	.	.	.	38·9	23·9
,, 28th, 5.30 ,,	.	.	.	.	39·0	25·6

MONKEY V.—*continued.*

	Mean.	Max.	Min.	Range.
4 Observations—Axilla .	39·0	39·3	38·9	0·4
2 ,, Groin .	38·8	38·8	38·8	0·0
6 ,, Rectum .	38·8	39·0	38·4	0·6
6 ,, Room .	25·3	26·1	23·9	2·2

MONKEY VI. (*M. rhæsus*).
♂ Adult.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 23rd, 2.30 p.m.	.	.	.	.	39·2	24·7
,, 25th, 5.30 ,,	39·1	39·3	38·8	38·8	38·8	25·6
,, 26th, 5.30 ,,	.	.	.	.	38·9	23·9
,, 27th, 5 ,,	38·7	38·8	.	.	38·4	23·3
,, 28th, 5.30 ,,	38·6	38·7	.	.	38·3	25·6

	Mean.	Max.	Min.	Range.
6 Observations—Axilla .	38·9	39·3	38·6	0·7
2 ,, Groin .	38·8	38·8	38·8	0·0
5 ,, Rectum .	38·7	39·2	38·3	0·9
5 ,, Room .	24·6	25·6	23·3	2·3

MONKEY VII. (*M. rhæsus*).
♂ Adult.

1901.	R. Axilla.	L. Axilla.	Rectum.	Room.
Feb. 22nd, 5.30 p.m.	39·1	39·0	39·0	26·1
,, 23rd, 5.30 ,,	.	.	38·8	25·3
,, 25th, 5.30 ,,	.	.	38·7	25·6
,, 26th, 5.30 ,,	39·0	39·1	39·1	23·9
,, 28th, 5.30 ,,	.	.	38·9	25·6
Mar. 4th, 5.30 ,,	38·7	38·8	38·5	26·1
,, 5th, 9.30 a.m.	.	.	38·2	25·8
,, ,, 5.30 p.m.	39·0	39·1	38·8	25·6
,, 6th, 5.30 ,,	.	.	39·2	25·0
,, 7th, 5.30 ,,	.	.	38·8	26·1
,, 8th, 5 ,,	.	.	39·1	24·4
,, 9th, 5.30 ,,	38·8	38·8	38·9	25·6
,, 10th, 5.30 ,,	38·7	38·7	38·6	25·8

	Mean.	Max.	Min.	Range.
12 Observations—Axilla .	38·9	39·1	38·7	0·4
13 ,, Rectum	38·8	39·2	38·2	1·0
13 ,, Room .	25·5	26·1	23·9	2·2

MONKEY VIII. (*M. rhœsus*).
♀ Not full grown.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 22nd, 5.30 p.m.	39·2	39·1	38·8	38·9	38·9	26·1
,, 25th, 5.30 ,,	.	.	.	.	38 6	25·6
,, 26th, 5.30 ,,	38·9	39·2	38·9	38·8	39·0	23·9
,, 28th, 5.30 ,,	38·8	39·0	.	.	38·9	25·6
Mar. 4th, 5.30 ,,	38·7	38·8	.	.	38·8	26·1
,, 5th, 5 ,,	39·0	39·1	.	.	38·6	25·8
,, 6th, 5.30 ,,	.	.	.	.	38·4	25·0
,, 7th, 5.30 ,,	.	.	.	.	38·8	26·1
,, 8th, 5.30 ,,	38·4	38·4	.	.	38·6	24·4
,, 9th, 5.30 ,,	39·2	39·1	.	.	38·9	25·6
,, 10th, 5.30 ,,		.	.	.	38·7	25·8

	Mean.	Max.	Min.	Range.
14 Observations—Axilla .	38·9	39·2	38·4	0·8
4 ,, Groin .	38 8	38·9	38·8	0·1
11 ,, Rectum .	38·8	39·0	38·4	0·6
11 ,, Room .	25 5	26·1	23·9	2·2

MONKEY IX. (*M. rhœsus*). ♂ Immature.

1901.	R. Axilla.	L. Axilla.	R. Groin.	L. Groin.	Rectum.	Room.
Feb. 22nd, 5 30 p.m.	39·3	39·2	39·1	.	39·3	26·1
,, 23rd, 2.30 ,,		.	.	.	39·2	25·3
,, 27th, 5.30 ,,	.	.	.	.	38·7	25·6
Mar. 4th, 5.30 ,,	38·8	38·9	.	.	38·9	26·1
,, 5th, 5 ,,	.	.	.	.	38·5	25·8
,, 6th, 5.30 ,,	.	.	.	.	39·1	25·0
,, 7th, 5.30 ,,	39·2	39·1	39·0	38·8	38·9	26·1
,, 8th, 5.30 ,,	.	.	.	.	38·7	24·4
,, 9th, 5.30 ,,	.	.	.	.	38·4	25·6
,, 10th, 5.30 ,,	39·1	39·0	.	.	38·9	25·8
,, 11th, 5.30 ,,	38·9	39·1	.	.	38·8	25·0

	Mean.	Max.	Min.	Range.
10 Observations—Axilla .	39·1	39·3	38·8	0·5
3 ,, Groin .	39·0	39·1	38 8	0·3
11 ,, Rectum .	38·9	39·3	38·4	0·9
11 ,, Room .	25·5	26·1	24·4	1·7

MONKEY X. (*M. rhœsus*). ♂ Adult.

1901.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 14th, 5.30 p.m. .	.	.	38·8	21·1
,, 15th, 5 ,, .	38·7	38·5	38·5	20·0
,, 16th, 5 ,, .	.	.	38·8	19·4
,, 17th, 5 ,, .	.	.	38·4	20·6

MONKEY X.—*continued.*

1901.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 18th, 5 p.m. .	.	.	38·9	21·1
,, 19th, 9.30 a.m. .	38·8	.	38·8	21·1
,, ,, 5 p.m. .	.	.	38·6	20·0
,, 20th, 9.30 a.m. .	.	.	38·4	20·0
,, ,, 5.30 p.m. .	39·1	39·0	38·8	19·7
,, 21st, 9.30 a.m. .	.	.	38·0	19·4
,, ,, 5.30 p.m. .	.	.	38·7	20·0
,, 22nd, 9 30 a.m .	.	.	38·3	19·4
,, ,, 5.30 p.m. .	.	.	38·8	19·7
,, 23rd, 9.30 a.m. .	37·9	38·0	37·8	21·1
,, ,, 5.30 p.m. .	.	.	38·6	20·6
,, 24th, 9.30 a m. .	.	.	37·7	21·1
,, ,, 5.30 p.m. .	38·9	38·8	38·8	20·0

	Mean.	Max.	Min.	Range.
9 Observations—Axilla.	38·6	39·1	37·9	1·2
17 ,, Rectum	38 5	38·9	37·7	1·2
17 ,, Room .	20·3	21 1	19·4	1·7

MONKEY XI. (*M. rhœsus*). ♂ Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Rom.
Jan. 17th, 12·30 p.m. .	38·0	37·9	38·0	15·6
,, 31st, 5 ,, .	.	.	38·2	25·6
Feb. 1st, 5 ,, .	.	.	38·4	25·0
,, 4th, 5 ,, .	38·3	38·4	38·2	25·0
,, 5th, 5 ,, .	.	.	38·4	24·4
,, 6th, 5 ,, .	38·9	38·8	38·9	25·0
,, 7th, 5 ,, .	39·0	38 9	38·8	25·0
,, 14th, 5 ,, .	38 8	38·8	38·6	21·7
,, 21st, 5 ,, .	.	.	38·6	20·0
,, 22nd, 2 ,, .	.	.	38·4	21·1
,, 25th, 5 ,, .	.	.	38·8	23·3

	Mean.	Max.	Min.	Range.
10 Observations—Axilla	38·6	39·0	37·9	1·1
11 ,, Rectum	38·5	38·9	38·0	0·9
11 ,, Room	22·9	25·6	15·6	10·0

MONKEY XII. (*M. rhœsus*). ♀ Adult

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
Jan. 20th, 9.30 a.m. .	38·4	38·4	38·3	18·3
,, ,, 4.30 p.m. .	38·8	38·7	38·5	20·0
,, 21st, 9.30 a.m. .	37·8	37·9	37·8	24·6
,, ,, 5 p.m. .	38·7	38·6	38·4	25·0
,, 22nd, 9.30 a.m. .	.	.	38·0	23·3
,, ,, 5.30 p.m. .	.	.	38·7	22·2

MONKEY XII.—*continued.*

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
Jan. 23rd, 9.30 a.m.	37·9	37·9	37·7	23·3
,, ,, 5.30 p.m.	38·8	38·9	38·9	23·9
,, 24th, 9.30 a.m.	.	.	37·9	23·3
,, 25th, 9.30 a.m.	.	.	38·4	25·0
,, ,, 5.30 p.m.	.	.	38·8	23·9
,, 26th, 9.30 a.m.	38·1	38·2	37·9	23·3
,, ,, 5.30 p.m.	38·6	38·8	38·6	23 3
,, 31st, 5 ,,	38·4	38·4	38·4	25·6
Feb. 18th, 5 ,,	.	.	39·2	21·1
,, 19th, 5 ,,	38·7	38·8	38·6	21·1
,, 20th, 5 ,,	38·7	38·8	38·7	23·3
,, 21st, 5 ,,	38·7	38·6	38·6	20·0
,, 22nd, 2 ,,	38·5	38·4	38·4	21·1
,, 25th, 5 ,,	38·9	39·0	38·8	23·3
,, 28th, 5 ,,	38·6	38·7	38·6	21·7
Mar. 3rd, 5 ,,	.	38·6	38·5	21·1
,, 4th, 5 ,,	.	38·9	38·8	25·0
,, 5th, 5 ,,	.	39·1	38·9	24·4
,, 7th, 5 ,,	38·4	38·6	38·4	21·1
,, 10th, 5 ,,	38·9	39·0	38·8	21·1
,, 12th, 5 ,,	38·7	38·8	38·7	22·8
,, 13th, 5 ,,	38·7	38·7	38·7	22·8
,, 14th, 5 ,,	39·1	39·1	38·1	22·2
,, 16th, 5 ,,	.	.	38·5	23·3
,, 18th, 5 ,,	38·8	38·9	38·8	23·9
,, 20th, 5 ,,	.	.	38 9	22·2
,, 28th, 5 ,,	38·9	38·9	38·7	21·1
,, 30th, 5 ,,	38·6	38·4	38·3	22·2

	Mean.	Max.	Min.	Range.
49 Observations—Axilla	38·6	39·1	37·8	1·3
34 ,, Rectum	38·5	39 2	37·7	1·5
34 ,, Room	22 6	25·6	18·3	7·3

MONKEY XII. (*M. rhœsus*). ♀ Adult.

This table shows the effect of muscular exercise on the temperature. The temperature was taken in the usual way after the animal had been resting half an hour; it was then set free and chased through the large room in which it was kept for a given period, at the end of which the temperature was immediately observed again.

1902.	L. Axilla.	Rectum.	Room.	Amount of Rise. Ax.	Amount of Rise. Rect.
Feb. 28th, 5 p.m.	38·7	38 6	21·7	.	.
,, ,, After 15 min. chase	39·8	39·8	.	1·1	1·2
Mar. 3rd, 5 p.m.	38·6	38·5	21·1	.	.
,, ,, After 10 min. chase	39·5	39·3	.	0·9	0·8
,, 4th, 5 p.m.	38·9	38·8	25	.	.
,, ,, After 10 min. chase	39·5	39·3	.	0·6	0·5
,, 5th, 5 p.m.	39·1	38·9	24·4	.	.
,, ,, After 10 min. chase	39·7	39·6	.	0·6	0·7
,, 7th, 5 p.m.	38·6	38·4	21·1	.	.
,, ,, After 30 min. chase	40·4	40·3	.	1·8	1·9
,, 10th, 5 p.m.	39·0	38·8	21·1	.	.
,, ,, After 20 min. chase	39·7	39·4	.	0·7	0·6
,, 12th, 5 p.m.	38·8	38·7	22·8	.	.
,, ,, After 45 min. chase	40·6	40·6	.	1·8	1·9

MONKEY XIII. (*M. rhœsus*). ♀ Immature.

1902.	Rectum.	Room.
Feb. 7th, 5 p.m.	38·9	24·4
,, 15th, 5 ,,	37·9	21·7
,, 17th, 5 ,,	38·7	22·2
,, 18th, 5 ,,	38·7	21·1
,, 19th, 5 ,,	38·8	21·1
,, 20th, 5 ,,	38·4	23·3
,, 21st, 5 ,,	38·2	20·0
,, 22nd, 5 ,,	37·3	21·1
,, 25th, 5 ,,	38·7	23·3

	Mean.	Max.	Min.	Range.
9 Observations—Rectum	38·4	38·9	37·3	1·6
9 ,, Room	22·0	24·4	20·0	4·4

MONKEY XIV. (*M. rhœsus*). ♀ Very old.

1902.	Rectum.	Room.
Feb. 15th, 5 p.m.	37·6	21·7
,, 17th, 5 ,,	38·7	22·2
,, 18th, 5 ,,	38·2	21·1
,, 19th, 5 ,,	38·6	21·1
,, 20th, 5 ,,	38·4	23·3
,, 21st, 5 ,,	38·9	20·0
,, 22nd, 5 ,,	38·6	21·1
,, 24th, 2 ,,	38·4	22·2

	Mean.	Max.	Min.	Range.
8 Observations—Rectum	38·4	38·9	37·6	1·3
8 ,, Room	21·6	23·3	20·0	3·3

MONKEY XV. (*M. rhœsus*). ♀ Small Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
March 20th, 4.30 p.m.	38·9	39·0	39·1	22·2
,, 24th, 5 ,,	39·2	39·1	38·9	22·2
,, 25th, 5 ,,	38·9	38·9	38·7	21·1

	Mean.	Max.	Min.	Range.
6 Observations—Axilla	39·0	39·2	38·9	0·3
3 ,, Rectum	38·9	39·1	38·7	0·4
3 ,, Room	21·8	22·2	21·1	1·1

MONKEY XVI. (*M. rhœsus*). ♀ Small Adult.

1902.	L. Axilla.	Rectum.	Room.
March 17th, 5 p.m. . .	39·2	38·9	21·1
,, 19th, 5 ,, . .	38·8	38·7	22·2
,, 20th, 5 ,, . .	38·7	38·6	22·2

	Mean.	Max.	Min.	Range.
3 Observations—Axilla .	38·9	39·2	38·7	0·5
3 ,, Rectum	38·7	38·9	38·6	0·3
3 ,, Room .	21·8	22·2	21·1	1·1

MONKEY XVII. (*M. rhœsus*). ♂ Small Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
March 17th, 5 p.m. .	38·9	38·9	38·6	21·1
,, 18th, 5 ,, .	38·9	39·1	38·7	21·1
,, 19th, 5 ,, .	38·9	38·7	38·4	22·2

	Mean.	Max.	Min.	Range.
6 Observations—Axilla .	38·9	39·1	38·7	0·4
3 ,, Rectum	38·6	38·7	38·4	0·3
3 ,, Room .	21·5	22·2	21·1	1·1

MONKEY XVIII. (*M. rhœsus*). ♀ Small Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
March 15th, 2 p.m. .	.	38·6	38·9	21·7
,, 17th, 5 ,, .	38·9	39·1	38·8	21·1
,, 18th, 5 ,, .	.	38·7	38·4	21·1
,, 19th, 5 ,, .	.	39·2	38·8	22·2
,, 20th, 5 ,, .	.	38·9	38·9	22·2
,, 22nd, 2 ,, .	.	38·8	38·7	23·3
,, 24th, 5 ,, .	.	39·2	38·9	22·2
,, 25th, 5 ,, .	.	39·1	38·8	23·3
,, 26th, 5 ,, .	.	39·2	38·8	22·8
,, 27th, 5 ,, .	.	39·1	38·9	22·2
April 2nd, 5·30 ,, .	.	39·1	38·8	21·7

	Mean.	Max.	Min.	Range.
12 Observations—Axilla.	39·0	39·2	38·6	0·6
11 ,, Rectum	38·8	38·9	38·4	0·5
11 ,, Room .	22·2	23·3	21·1	2·2

MONKEY XIX. (*M. rhœsus*). ♀ Large Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 1st, 5 p.m. . .	38·9	39·0	39·1	21·7
,, 2nd, 5 ,, . .	38·6	.	38·4	21·1
,, 5th, 5 ,, . .	38·6	38·7	38·7	18·3
,, 6th, 5 ,, . .	38·9	38·8	38·8	20·0
,, 7th, 5 ,, . .	.	38·4	38·2	22·2
,, 9th, 5 ,, . .	39·0	38·9	38·6	23·3
,, 12th, 5 ,, . .	.	39·2	39·1	20·0
,, 13th, 5 ,, . .	38·7	38·8	38·3	21·1

	Mean.	Max.	Min.	Range.
13 Observations—Axilla.	38·8	39·2	38·4	0·8
8 ,, Rectum	38·7	39·1	38·2	0·9
8 ,, Room .	21·0	23·3	18·3	5·0

MONKEY XX. (*M. rhœsus*). ♂ Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 1st, 5 p.m. . .	39·0	38·9	39 0	21·7
,, 2nd, 5 ,, . .	.	39·1	39·2	21·1
,, 5th, 5 ,, . .	39·1	39·2	38·7	18·3
,, 6th, 5 ,, . .	39·1	38·9	38·7	20·0
,, 7th, 5 ,, . .	39·1	.	39·0	22·2
,, 9th, 5 ,, . .	39·1	39·1	39·1	23·3
,, 12th, 5 ,, . .	39·1	.	39·1	20·0
,, 13th, 5 ,, . .	39·2	39·0	38·9	21·1

	Mean.	Max.	Min.	Range.
13 Observations—Axilla.	39·0	39·2	38·9	0·3
8 ,, Rectum	39·0	39·2	38·7	0·5
8 ,, Room .	21·0	23·3	18·3	5·0

MONKEY XXI. (*M. rhœsus*). ♂ Large Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 1st, 5 p.m. . .	.	38·4	38·4	21·1
,, 9th, 5 ,, . .	38·9	39·0	38·9	23·3
,, 13th, 5 ,, . .	38·9	39·0	38·8	21·1

	Mean.	Max.	Min.	Range.
5 Observations—Axilla .	38·8	39·0	38·4	0·6
3 ,, Rectum	38·7	38·9	38·4	0·5
3 ,, Room .	21·8	23·3	21·1	2·2

MONKEY XXII. (*M. rhœsus*). ♂ Small Adult.

1902.	L. Axilla.	Rectum.	Room.
June 16th, 5 p.m. . .	39·0	38·7	22·2
,, 17th, 5 ,, . .	38·8	38·8	23·3
,, 18th, 5.30 ,, . .	39·2	38·9	21·7
,, 19th, 5.30 ,, . .	38·8	38·6	21·1

	Mean.	Max.	Min.	Range.
4 Observations—Axilla .	38·9	39·2	38·8	0·4
4 ,, Rectum	38·8	38·9	38·6	0·3
4 ,, Room .	22·1	23·3	21·1	2·2

MONKEY XXIII. (*M. rhœsus*). ♀ Immature.

1902.	L. Axilla.	Rectum.	Room.
June 16th, 5 p.m. . .	39·0	39·0	22·2
,, 17th, 5 ,, . .	39·2	39·0	23·3
,, 18th, 5.30 ,, . .	39·0	38·7	21·7
,, 19th, 5.30 ,, . .	39·2	38·8	21·1

	Mean.	Max.	Min.	Range.
4 Observations—Axilla .	39·1	39·2	39·0	0·2
4 ,, Rectum	39·0	39·0	38·7	0·3
4 ,, Room .	22·1	23·3	21·1	2·2

MONKEY XXIV. (*M. rhœsus*). ♂ Immature.

1902.	L. Axilla.	Rectum.	Room.
Oct. 29th, 5 p.m. . . .	38·6	38·1	22·2
,, 30th, 9.30 a.m. . .	37·9	37·7	21·1
,, ,, 2.30 p.m. . .	37·8	37·6	21·7
,, ,, 5.30 ,, . .	38·7	38·4	21·9
,, 31st, 9.30 a.m. . .	38·1	37·8	20·6
,, ,, 2.30 p.m. . .	37·8	37·4	20·8
,, ,, 5.30 ,, . .	38·8	38·6	21·7
Nov. 3rd, 5.30 ,, . .	38·1	37·8	21·9
,, 4th, 9.30 a.m. . .	37·9	37·8	22·2
,, ,, 2.30 p.m. . .	38·9	38·7	21·9
,, ,, 5.30 ,, . .	38·8	38·7	21·1
,, 7th, 9.30 a.m. . .	37·7	37·6	21·9
,, ,, 2.30 ,, . .	38·7	38·6	22·8
,, ,, 5.30 ,, . .	38·9	38·7	21·9

MONKEY XXIV.—*continued.*

	Mean.	Max.	Min.	Range.
14 Observations—Axilla	38·3	38·9	37·7	1·2
14 ,, Rectum	38·1	38·7	37·4	1·3
14 ,, Room	21·7	22·8	20·6	2·2

MONKEY XXV. (*M. rhœsus*). ♀ Immature.

1902.	L. Axilla.	Rectum.	Room.
Oct. 29th, 5 p.m. . .	38·7	38·4	22·2
,, 30th, 9.30 a.m. . .	37·3	37·1	21·1
,, ,, 2.30 p.m. . .	37·9	37·8	21·7
,, ,, 5.30 ,, . .	38·4	38·2	21·9
,, 31st, 9.30 a.m. . .	38·4	38·1	20·6
,, ,, 2.30 p.m. . .	38·3	37·9	20·8
,, ,, 5.30 ,, . .	38·9	38·6	21·7
Nov. 3rd, 5.30 ,, . .	38·5	38·4	21·9
,, 4th, 9.30 a.m. . .	37·8	37·6	22·2
,, ,, 2.30 p.m. . .	37·8	37·4	21·9
,, ,, 5.30 ,, . .	38·4	38·1	21·1
,, 7th, 9.30 a.m. . .	37·4	37·3	21·9
,, ,, 2.30 p.m. . .	38·7	38·4	22·8
,, ,, 5.30 ,, . .	38·2	37·9	21·9

	Mean.	Max.	Min.	Range.
14 Observations—Axilla	38·2	38·9	37·3	1·6
14 ,, Rectum	38·0	38·6	37·1	1·5
14 ,, Room	21·7	22·8	20·6	2·2

MONKEY XXVI. (*M. rhœsus*). ♂ Large Adult.

1902.	L. Axilla	Rectum.	Room.
Nov. 21st, 9.30 a.m. . .	38·4	38·4	23·9
,, ,, 5.30 p.m. . .	38·4	38·1	23·3
,, 24th, 9.30 a.m. . .	38·0	37·8	23·1
,, ,, 5.30 p.m. . .	38·9	38·7	22·2
,, 25th, 9.30 a.m. . .	38·4	38·0	23·9
,, ,, 5.30 p.m. . .	38·7	38·6	23·1
,, 28th, 9.30 a.m . .	37·4	37·3	25·3
,, ,, 5.30 p.m. . .	38·8	38·7	21·4
,, 29th, 9.30 a.m. . .	38·0	37·8	24·7
Dec. 1st, 9.30 ,, . .	38·6	38·4	23·3
,, ,, 5.30 p.m. . .	38·9	38·6	23·3

	Mean.	Max.	Min.	Range.
11 Observations—Axilla	38·4	38·9	37·4	1·5
11 ,, Rectum	38·2	38·7	37·3	1·4
11 ,, Room	23·4	24·7	21·4	3·3

MONKEY XXVII. (*M. rhœsus*). ♀ Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 14th, 9 a.m.	37·9	37·9	37·8	21·1
,, ,, 12.30 p.m.	38·6	38·7	38·3	21·7
,, ,, 4.30 ,,	38·7	38·7	38·7	21·1
,, ,, 9 ,,	37·9	37·9	37·8	21·7
,, ,, 11.45 ,,	37·0	36·9	36·8	21·1
,, 15th, 9 a.m.	37·7	37·6	37·4	21·1
,, ,, 12 (noon)	38·2	38·3	38·3	21·1
,, ,, 4.30 p.m.	38·9	38·8	38·8	21·1
,, ,, 9 ,,	37·4	37·3	37·1	21·7
,, ,, 11.45 ,,	36·1	35·9	35·8	21·1
,, 16th, 9 a.m.	37·4	.	37·0	21·1
,, ,, 12 (noon)	37·8	37·7	37·7	21·7
,, ,, 4.30 p.m.	38·3	38·4	38·1	21·1
,, ,, 9 ,,	37·4	37·4	36·7	21·1
,, ,, 12 (midnight)	36·4	36·2	36·5	20·6

	Mean.	Max.	Min.	Range.
29 Observations—Axilla	37·7	38·9	35·9	3·0
15 ,, Rectum	37·5	38·8	35·8	3·0
15 ,, Room	21·2	21·7	20·6	1·1

MONKEY XXVIII. (*M. rhœsus*). ♀ Adult.

1902.	R. Axilla.	L. Axilla.	Rectum.	Room.
May 14th, 9 a.m.	38·1	38·2	38·1	21·1
,, ,, 12.30 p.m.	38·4	38·4	38·4	21·7
,, ,, 4.30 ,,	38·9	39·1	38·9	21·1
,, ,, 9 ,,	37·9	37·9	37·9	21·7
,, ,, 11.45 ,,	37·3	37·4	37·0	21·1
,, 15th, 9 a.m.	38·2	38·2	38·2	21·1
,, ,, 12 (noon)	38·9	38·8	38·7	21·1
,, ,, 4.30 p.m.	38·9	39·0	38·9	21·1
,, ,, 9 ,,	37·8	37·9	37·7	21·7
,, ,, 11.45 ,,	36·9	36·9	36·8	21·1
,, 16th, 9 a.m.	37·9	37·8	37·8	21·1
,, ,, 12 (noon)	39·0	39·1	39·0	21·7
,, ,, 4.30 p.m.	39·3	39·0	38·8	21·1
,, ,, 9 ,,	37·6	37·5	37·0	21·1
,, ,, 12 (midnight)	37·8	38·0	37·3	20·6

	Mean.	Max.	Min.	Range.
30 Observations—Axilla	38·2	39·3	36·9	2·4
15 ,, Rectum	38·0	39·0	36·8	2·2
15 ,, Room	21·2	21·7	20·6	1·1

MONKEY XXIX. (*M. rhœsus*). ♂ Immature.

1902.	L. Axilla.	Rectum.	Room.
May 14th, 9 a.m.	38·0	37·8	21·1
,, ,, 12 30 p.m.	38·1	38·3	21·7
,, ,, 4.30 ,,	38·7	38·7	21·1
,, ,, 9 ,,	38·4	38·4	21·7
,, ,, 11.45 ,,	37·2	37·2	21·1
,, 15th, 9 a.m.	37·8	37·8	21·1
,, ,, 12 (noon)	38·3	38·2	21·1
,, ,, 4.30 p.m.	38·7	38·5	21·1
,, ,, 9 ,,	36·9	37·2	21·7
,, ,, 11.45 ,,	36·6	36·6	21·1
,, 16th, 9 a.m.	38·5	38·6	21·1
,, ,, 12 (noon)	38·2	38·2	21·7
,, ,, 4.30 p.m.	38·9	38·6	21·1
,, ,, 9 ,,	37·6	37·4	21·1
,, ,, 12 (midnight)	37·4	37·0	20·6

	Mean.	Max.	Min.	Range.
15 Observations—Axilla.	37·9	38·9	36·6	2·3
15 ,, Rectum	37·9	38·7	36·6	2·1
15 ,, Room.	21·2	21·7	20·6	1·1

MONKEY XXX. (*M. rhœsus*). ♂ Probably immature.

1902.	R Axilla.	Rectum.	Room.
May 26th, 8.30 p.m.	38·7	38·2	21·1
,, ,, 12 (midnight)	38·1	37·9	21·9
,, 27th, 4.45 a.m.	37·2	36·9	20·0
,, ,, 8 ,,	37·6	37·7	20·0
,, ,, 12 (noon)	38·3	37·9	21·1
,, ,, 7 p.m.	38·9	38·6	21·7
,, ,, 10.30 ,,	38·0	37·9	21·7
,, 28th, 3 a.m.	36·1	35·9	20·0
,, ,, 6.30 ,,	36·5	36 5	19·4
,, ,, 9 ,,	37·9	37·6	21·1
,, ,, 12 (noon)	38·2	38·1	21·1
,, ,, 4.30 p.m.	38·3	38·2	20·6
,, ,, 7 ,,	39·3	38·9	20·6
,, ,, 7.45 ,,	39·0	38·9	21·4
,, ,, 10.30 ,,	38·2	38·1	21·1
,, 29th, 12.15 a.m.	37·4	37·4	21·7
,, ,, 2 ,,	36·9	36·8	20·6
,, ,, 4.30 ,,	36·8	36·6	20·0
,, ,, 7.30 ,,	36·8	36·7	19·7
,, ,, 12 (noon)	37·9	37·8	20·3
,, ,, 4.45 p.m.	38·4	38·3	20·6
,, ,, 6.15 ,,	38·8	38·6	20·6
,, ,, 7.15 ,,	38·9	38·9	20·8
,, ,, 7.45 ,,	39·1	38·9	20·8
,, ,, 10.45 ,,	38·1	37·8	21·1
,, ,, 12 (midnight)	37·9	37·8	21·4
,, 30th, 5.15 a.m.	36·3	36·0	19·7
,, ,, 7 ,,	37·1	36·8	19·4
,, ,, 8 ,,	37·2	37·0	20·6
,, ,, 12.15 p.m.	37·8	37·8	20·6
,, ,, 6 ,,	38·6	38·3	20·6
,, ,, 7 ,,	38·9	38·8	20·6
,, ,, 8 ,,	38·3	38·2	21·1

MONKEY XXX.—*continued.*

1902.	R. Axilla.	Rectum.	Room.
May 30th, 12 (midnight) .	37·6	37·4	21·7
,, 31st, 1.15 a.m. . .	37·3	37·2	21·4
,, ,, 2 ,, . .	36·7	36·6	21·1
,, ,, 5 p.m. . .	38·2	37·9	19·4
,, ,, 6 ,, . .	38·2	38·2	19·4
,, ,, 7 ,, . .	38·6	38·5	19·7
,, ,, 8 ,, . .	38·6	38·2	20·3
,, ,, 8.45 ,, . .	38·3	38·2	19·4
,, ,, 10.45 ,, . .	37·8	37·6	19·4
,, ,, 12 (midnight) .	37·6	37·2	20·6
June 1st, 1 a.m. . .	37·8	37·6	21·1
,, ,, 2 ,, . .	37·4	37·2	21·7
,, ,, 3.15 ,, . .	36·8	36·6	21·4
,, ,, 5.30 ,, . .	36·3	36·2	21·1
,, ,, 7 ,, . .	36·7	36·6	19·4
,, ,, 8 ,, . .	36·9	36·7	18·9
,, ,, 9 ,, . .	37·1	36·9	18·6
,, ,, 10 ,, . .	37·4	37·2	18·6
,, ,, 11 ,, . .	37·9	37·9	19·4
,, ,, 12 (noon) .	37·5	37·6	19·4
,, ,, 1 p.m. . .	38·0	37·9	19·4
,, ,, 2.15 ,, . .	38·2	38·1	19·4
,, ,, 3.15 ,, . .	38·2	38·2	19·4
,, ,, 4 ,, . .	38·1	37·9	18·9
,, ,, 5.15 ,, . .	38·4	38·4	18·9
,, ,, 6.30 ,, . .	38·2	38·1	19·4
,, ,, 7.15 ,, . .	39·0	38·9	19·7
,, ,, 9.30 ,, . .	37·7	37·4	20·0
,, ,, 10.45 ,, . .	37·2	37·2	20·0
,, 2nd, 3 a.m. . .	35·4	35·1	18·9
,, ,, 4.15 ,, . .	36·4	36·1	19·7
,, ,, 5 ,, . .	36·8	36·5	20·0
,, ,, 6 ,, . .	36·8	36·4	20·3
,, ,, 7 ,, . .	37·0	36·7	20·3
,, ,, 8 ,, . .	37·1	36·9	20·6
,, ,, 12.30 p.m. . .	38·0	37·8	18·6
,, ,, 5.30 ,, . .	38·4	38·2	20·6
,, ,, 6.30 ,, . .	38·7	38·3	20·3
,, ,, 7.15 ,, . .	38·6	38·3	20·3
,, ,, 8 ,, . .	38·4	38·1	20·3
,, ,, 9.15 ,, . .	38·1	37·9	20·3
,, ,, 10.15 ,, . .	37·8	37·7	20·6
,, ,, 11.15 ,, . .	37·4	37·4	20·8
,, ,, 12 (midnight) .	36·8	36·7	20·8

	Mean.	Max.	Min.	Range.
77 Observations—Axilla	37·8	39·3	35·4	3·9
77 ,, Rectum	37·6	38·9	35·1	3·8
77 ,, Room.	20·2	21·9	18·6	3·3

MONKEY XXXI. (*M. rhœsus*). ♂ Small Adult.

1902.	L. Axilla.	Rectum.	Room.
June 20th, 9 p.m. . .	39·2	38·9	18·9
,, ,, 10 ,, . .	38·6	38·5	19·4
,, ,, 12 (midnight) .	38·5	38·3	19·7
,, 21st, 1 a.m. . .	38·7	38·4	19·2
,, ,, 2 ,, . .	38·0	37·8	20·0
,, ,, 6 ,, . .	37·9	37·8	20·6
,, ,, 8 ,, . .	37·5	37·3	21·1
,, ,, 10 ,, . .	38·2	37·9	20·8
,, ,, 1 p.m. . .	37·7	37·6	20·6
,, ,, 2 ,, . .	37·6	37·3	20·8
,, ,, 3 ,, . .	38·4	38·1	20·0
,, ,, 4 ,, . .	38·6	38·6	19·4
,, ,, 5 ,, . .	38·9	38·8	19·7
,, ,, 6 ,, . .	38·3	38·1	20·6
,, ,, 7 ,, . .	38·8	38·5	20·3
,, ,, 10.15 ,, . .	39·2	39·1	20·0
,, ,, 11.30 ,, . .	38·7	38·4	21·1
June 22nd, 12.15 a.m. . .	38·4	38·0	21·4
,, ,, 1 ,, . .	38·7	38·2	20·8
,, ,, 2 ,, . .	37·8	37·6	20·6
,, ,, 3 ,, . .	37·4	37·3	20·6
,, ,, 4 ,, . .	37·8	37·5	20·3
,, ,, 5 ,, . .	36·8	36·7	20·0
,, ,, 6 ,, . .	37·7	37·3	20·4
,, ,, 7 ,, . .	36·7	36·4	20·8
,, ,, 8 ,, . .	37·8	37·6	20·6
,, ,, 9 ,, . .	38·2	38·1	20·3
,, ,, 10 ,, . .	37·7	37·6	21·1
,, ,, 12 (noon) . .	38·4	38·3	19·7
,, ,, 3 p.m. . .	38·1	37·7	20·3
,, ,, 4 ,, . .	38·7	38·4	20·0
,, ,, 6 ,, . .	38·8	38·7	19·7
,, ,, 8 ,, . .	38·2	38·1	20·6
,, ,, 10 ,, . .	38·9	38·2	20·8
,, ,, 11 ,, . .	37·8	37·4	21·7
,, ,, 12 (midnight) .	37·7	37·6	21·7

	Mean.	Max.	Min.	Range.
36 Observations—Axilla	38·2	39·2	36·7	2·5
36 ,, Rectum	38·0	39·1	36·4	2·7
36 ,, Room.	20·4	21·7	18·9	2·8

From the foregoing observations the following general conclusions were arrived at:—1. *Muscular exercise raises the temperature of the monkey to a very marked extent.* This is well illustrated in the case of monkey No. XII. (p. 69). A chase of 10 minutes was sufficient to raise the temperature of the axilla from 38·6° C. to 39·5° C. (0·9° C.), and that of the rectum from 38·5° C. to 39·3° C. (0·8° C.), while after a chase of 45 minutes the temperature of the axilla rose from 38·8° C. to 40·6° C. (1·8° C.), and that of the rectum from 38·7° C. to 40·6° C. (1·9° C.). The effect of

muscular exercise on the body temperature has been observed in many other animals, including man; but the monkey seems to be particularly susceptible to this influence, and for this reason it is evident that in all observations made with a view to determine the normal temperature of these animals, struggling, either immediately before or during the operation, will give an incorrect reading. This will be considered more fully subsequently.

2. *In the monkey the temperature of the axilla is, as a rule, higher than that of the rectum.* In 553 observations made on 26 animals up to this date, the mean temperature of the axilla was 38·76 and of the rectum 38·61, giving a difference of 0·15 in favour of the axilla. Every source of fallacy was thought of and guarded against as far as possible, such as the monkey sitting on the cold floor for some time before the thermometer was inserted, which might possibly lower the temperature of the rectum. Sometimes the temperature of the rectum was taken first, and sometimes that of the axilla, but this was found to make no difference in the relative readings. The time of application of the thermometer was the same in both cases—two minutes. For absolute accuracy this was probably too short, but the difficulty of inducing the animal to remain quiet for a longer period was sometimes very great, and the error introduced by forcibly holding it would have been greater than that due to too short an application of the thermometer.

The same fact was observed in 1818 by Davy (1) in Simia Aygula in Ceylon. In the single case which he records he found the rectal temperature to be 103·5° F. (39·9° C.), and that of the axilla 104·5° F. (40·3° C.), showing a difference of 1° F. or about 0·4° C. The temperature of the mouth of a marmot awakening from its winter sleep has been found by Pembrey (2) to be sometimes from 2° C. to 3° C. above that of the rectum, and the same has been found in other hibernating mammals by Quincke (3) and others. Pembrey found that the difference is most marked when the marmot's temperature is rising rapidly during its awakening; there is little difference when the animal is torpid, and when it is fully awake the rectal temperature is about a degree higher than the buccal. In man the rectal temperature is stated by most observers to be from 0·2° C. to 0·6° C. higher than that of the axilla, although Ringer and Stewart (4) assert that there is in reality no difference between the temperatures of the mouth, axilla, and rectum, if due care be taken and sufficient time allowed. The axilla in the monkey is always dry, and it can be so well closed that it is to all intents and purposes an internal cavity, while, on the other hand, the monkey is not so well developed in the gluteal region relatively as man, and consequently the rectum is not so well protected, and the muscular development of the fore limbs being greater than that of the hind limbs, there may also be a difference in the vascularity.

Diurnal Variation of Body Temperature.

So far no consideration had been given to the question of the presence or absence of a diurnal variation in the temperature. By far the greater number of the observations had been made in the afternoon, usually between 5 and 6 o'clock, but one week, having occasion to be working in the laboratory until late in the evening, we made observations at 9 a.m. and at 12.30 p.m., 4.30 p.m., 9 p.m. and 11.45 p.m. respectively on three consecutive days on three monkeys, and found distinct evidence of a diurnal rhythm in each case. The highest temperatures were recorded between 4 and 5 p.m., and the lowest between 11 and 12 p.m.; the variation was very regular and the range a considerable one, as may be seen by an inspection of the tabulated records of monkeys, XXVII., XXVIII., and XXIX. (p. 72).

To investigate this diurnal variation more fully we selected a very quiet animal—monkey XXX.—and took readings at short intervals throughout the twenty-four hours for eight days consecutively. During this time the monkey was confined in a cage in a warm room, the temperature of which varied only from about 18° C. to 22° C. throughout the whole period. It always had a plentiful supply of fruit, etc., but was not fed at regular intervals. In the monkey the food is not always ingested at the time the animal is supplied with it, for it usually fills its cheek pouches and empties them at its leisure, it may be some considerable time later. At that season of the year (May) daylight appeared between 3 a.m. and 4 a.m., but the shutters were not removed from the windows till about 8 a.m. The cage in which it was confined was large enough to admit of its moving about freely, but did not allow it to take very active muscular exercise, yet notwithstanding this the daily rhythm was very regular and distinct, and the range wide. The minimal period was between 3 a.m. and 5 a.m., and the maximal period between 6 p.m. and 8 p.m. When plotted out, the curves of the axillary, rectal, and room temperatures show that the axillary temperature is in most cases higher than the rectal, but that the two vary together, and that the curve of body temperature varies independently of that of the room, for very frequently when the one is falling the other is rising.

Subsequently another experiment of the same kind was made with another monkey under the same conditions as obtained in the last case, and the result was similar (see table—monkey XXXI., p. 73). The variation was not so regular, and there were more secondary waves in the primary, but it was of the same type, and the minimal and maximal periods occurred in the early morning and late in the afternoon respectively.

On glancing at the temperature curves of monkeys XXX. and XXXI., their close similarity to that seen in the clinical chart of a hectic patient was at once evident, and the possibility suggested itself that these animals, although apparently healthy, might be suffering from some form of tubercular disease, a condition not very uncommon in monkeys kept in confinement. The five monkeys (XXVII., XXVIII., XXIX., XXX.,

and XXXI.) had come to the laboratory from the same source. They were particularly tame and very suitable for our purpose. They remained in the laboratory two or three months after our observations had been made, during which time they gained rather than lost weight, which is strong presumptive evidence that they were not tuberculous, but when they were afterwards used for another purpose no post-mortem examination of the internal organs was made, and so it could not be definitely stated that these animals were free from tuberculous disease and that the curves obtained were from normal animals. These curves, however, were found to be exactly similar to those got during our later investigations from monkeys who were undoubtedly free from tuberculous disease, so that they may be fairly claimed as normal curves.

PART II.

Introduction.

We then resolved to make a more extended series of observations with the view of investigating more accurately the character and amplitude of the normal wave and ascertaining the factors which determine its occurrence. The commonly assigned causes of the normal fluctuations of body temperature are:—muscular exercise, sleep, ingestion of food, inanition, light, and the temperature of the surrounding medium. The exact relationship between these various influences and the diurnal temperature variation has never been satisfactorily demonstrated, the relative importance of the factors has not been estimated, nor has it ever been conclusively shown that the variation depends upon these various factors. Carter (5) and others have found that the curves of heat production and heat loss do not coincide with the temperature curve. If this diurnal wave be due to the combined action of the various factors enumerated above, then it might be expected that any modification of them would produce a change in the form of the curve, or, in the simplest and most complete case, total inversion of the daily routine would cause a corresponding change in the curve. This had already been tried in man by several observers, but the conclusions arrived at are contradictory. However, in the most recent and at the same time most carefully planned and executed experiments on this question, carried out by Benedict (6), this observer was unable to produce an inversion of the temperature curve by inverting the daily routine of life. This would tend to show that either the temperature wave was not caused by the alternation of rest and activity, or that the control or co-ordination of the causal factors was sufficiently perfect to maintain a practically constant temperature with no discoverable inversion of the swing, or that there existed a habit of temperature variation, whatever the actual causal factors of the variation be, too powerful to be eliminated during the course of a short series of observations.

As noted above, our previous observations had shown that in the monkey, after every precaution against fallacy had been taken, there existed a wave of an amplitude

considerably in excess of that found in man. At the same time it was evident that the temperature of the monkey was exceedingly susceptible to variations in muscular activity, showing very considerable rises after even short periods of active exercise. Taking these two facts into consideration, we concluded that the temperature control in the monkey was less perfect than in man, inasmuch as, so far as our investigations went, variations in the controlling factors caused relatively greater variations in the body temperature.

Method of Procedure.

We therefore decided to attempt an experiment on the monkey similar to that which Mosso (7) and Benedict (6) had made in man, extending over a sufficiently long period and in a sufficient number of animals to make the results conclusive. We took all precautions to obviate fallacy which seemed to us necessary from our previous experience. We selected only animals which submitted to the operation without struggling. They were fed at regular intervals and disposed of their food at their leisure. They were kept in a quiet part of the laboratory, in a large room, where they were allowed complete freedom to roam about, and as the most important part of the experiment was made during the Easter vacation, the outside disturbances were reduced to a minimum. The room was artificially heated, and the temperature kept as constant as possible night and day. Variations in the room temperature within these narrow limits (15 to 20° C. for the greater part of the time) were found to have no appreciable influence on the curve of body temperature. Ventilation was good, and all the conditions were as favourable as it was possible to make them.

Before beginning our observations, all the monkeys chosen were tested with Koch's tuberculin, but none of them gave any reaction. One animal, however, was found to have tuberculosis post-mortem, but its temperature after the fourteenth day exhibited marked peculiarities, sufficient of themselves to distinguish it from the curves of the others, and it is not included in the number from which the various curves were obtained. One of our monkeys developed acute phosphorus poisoning from having eaten some lucifer matches, and died within a few hours, but another of the same species was substituted for it. Its temperature readings up till the day on which it ate the poison are included in the averages. Post-mortem examination showed no trace of tuberculous disease.

The number and description of the animals, not including the one which was found to have tuberculosis, may be briefly given as follows:—

Monkey A (*Macacus rhœsus*). ♂ adult (died of acute phosphorus poisoning).
„ B „ „ ♂ „ (substituted for A).
„ C „ „ ♀ immature.
„ D („ *cyanomolgus*). ♂ aged.
„ E (*Papio hamadryas*). ♀ adult.
„ F (*Cercopithecus patas*). ♀ adult.

After these observations were concluded, the monkeys were used in the laboratory for other purposes, and when killed within a few weeks of the conclusion of the experiment, they were found on post-mortem examination to be healthy and free from any trace of tuberculosis.

The monkeys were tied up at 9 p.m. and let loose again at 9 a.m., when work in the laboratory commenced for the day. For this reason the resting and active periods were made in the first stage of the experiment from 9 to 9. It has been shown above that the axillary temperature is as reliable as the rectal, and we selected the former for the reason that the readings could be so much more easily obtained. In fact, during the resting periods the thermometer could be slipped into the axilla almost without awakening the animals, and with so little disturbance that if they did wake up they were generally asleep again before the observer left the room. After a considerable preliminary period, during which we took unrecorded readings in order to accustom them to the hours and conditions of life and to the necessary manipulations, two-hourly observations were recorded throughout the twenty-four hours. From these records a curve was plotted out in each case showing the mean diurnal wave for each of the periods, and a mean curve was also calculated for the whole five monkeys for each period. These were found to correspond in every respect with those got during our earlier observations. The actual curve for any given day only differed from the mean curve in showing more irregularities, as may be seen by comparing the coloured chart in the Appendix, which gives the results in three monkeys *in extenso*, with the corresponding charts in the text (figs. 1, 2, 3, 8, 9, 10).

Division of Experiment into Six Periods.

These preliminary remarks suffice to show the general arrangements for the whole duration of the work. The experiment was divided into six periods. In the first or normal period the incidence of night and day was the natural one—the monkeys slept or rested during the night and were active during the day. In the second period the conditions were reversed—they slept during the day and were active during the night; and the third period was merely a modification of the second. During the fourth period they were kept in total darkness, and during the fifth in continuous light. The sixth period deals with the effect of alimentation on the mean temperature and its range.

Results.

The readings are given in tabular form in the following pages for each monkey, A, B, C, D, E, and F, as they were recorded, with the corresponding room temperature, and the mean temperature of the whole for each hour is calculated.

PERIOD I.

1903.	A.	C.	E.	D.	F.	Mean.	Room.
Mar. 23rd, 1 p.m.	39·3	39·8	.	.	.	.	20·6
,, ,, 4 ,,	39·4	39·6	.	.	.	.	16·4
,, 24th, 1 ,,	39·4	39·4	.	.	.	.	13·3
,, ,, 4 ,,	39·4	39·2	.	.	.	.	14·4
,, 25th, 1 ,,	39·3	39·1	.	.	.	.	14·4
,, ,, 4 ,,	.	39·2	.	.	.	.	.
,, 26th, 1 ,,	39·3	38·8	.	.	.	.	15·6
,, ,, 4 ,,	38·9	38·9	.	.	.	.	15·6
,, ,, 9 ,,	.	39·4	.	.	.	.	.
,, 27th, 11 a.m.	39·3	38·8	.	.	.	.	12·8
,, ,, 1 p.m.	39·4	39·0	38·3	37·9	.	38·7	14·4
,, ,, 4 ,,	39·6	39·0	38·5	38·1	.	38·8	15·6
,, 28th, 9 a.m.	38·8	38·3	.	.	.	.	14·4
,, ,, 1 p.m.	38·4	38·9	38·4	37·4	.	38·3	15·6
,, 30th, 1 ,,	39·3	39·0	38·2	37·8	37·3	38·3	14·4
,, ,, 4 ,,	40·0	39·3	38·7	38·0	37·6	38·7	15·6
,, 31st, 9 a.m.	38·8	38·2	.	.	37·4	.	12·2
,, ,, 11 ,,	39·0	39·1	38·2	37·4	37·6	38·3	12·8
,, ,, 1 p.m.	38·9	38·7	38·2	37·3	37·3	38·1	13·3
,, ,, 3 ,,	39·1	39·0	38·6	37·8	37·6	38·4	12·8
,, ,, 5 ,,	39·5	39·1	38·9	38·1	37·7	38·9	13·3
,, ,, 7 ,,	39·7	38·8	39·1	38·8	37·6	38·8	13·3
,, ,, 9 ,,	38·8	38·8	39·2	38·1	37·8	38·5	15·6
,, ,, 11 ,,	38·8	38·7	39·0	37·2	38·4	38·4	15·6
Apr. 1st, 1 a.m.	38·2	38·2	38·6	37·1	38·1	38·0	12·8
,, ,, 3 ,,	37·3	37·9	38·3	36·4	38·1	37·6	14·4
,, ,, 5 ,,	37·7	38·2	39·0	36·7	37·6	37·8	15·6
,, ,, 7 ,,	38·2	38·4	38·0	37·0	38·7	38·1	15·6
,, ,, 9 ,,	38·7	38·4	38·4	37·0	38·5	38·2	15·6
,, ,, 11 ,,	38·6	38·7	38·4	37·7	38·7	38·4	16·7
,, ,, 1 p.m.	38·9	38·6	38·4	37·6	38·4	38·4	16·7
,, ,, 3 ,,	39·1	38·8	38·9	38·0	38·6	38·7	17·2
,, ,, 5 ,,	.	.	.	.	.	.	.
,, ,, 7 ,,	38·7	39·0	38·8	37·9	38·8	38·6	16·7
,, ,, 9 ,,	38·1	38·4	38·3	37·9	38·6	38·3	16·1
,, ,, 11 ,,	38·2	38·3	38·4	37·9	38·7	38·3	16·7
,, 2nd, 1 a.m.	38·0	38·2	38·3	.	.	.	16·7
,, ,, 11 ,,	38·7	38·6	38·9	37·8	38·1	38·4	16·7
,, ,, 1 p.m.	39·0	38·8	38·7	37·9	38·3	38·5	15·0
,, ,, 3 ,,	39·1	38·9	39·1	38·3	37·8	38·6	15·0
,, ,, 5 ,,	.	39·3	38·3	38·0	38·8	38·6	.
,, ,, 7 ,,	36·5	38·9	38·7	38·3	38·3	38·4	14·4
,, ,, 9 ,,	Dead.	.	.	.	.	.	.
,, ,, 11 ,,	.	37·9	37·9	37·3	38·0	37·8	15·5
,, 3rd, 1 a.m.	.	37·9	37·7	36·6	37·6	37·5	15·5
,, ,, 3 ,,	.	37·8	36·8	36·2	37·4	37·1	16·8
,, ,, 5 ,,	.	37·3	37·1	36·2	37·7	37·1	16·7
,, ,, 7 ,,	.	37·8	37·3	35·9	37·5	37·1	17·2
,, ,, 9 ,,	.	38·1	37·3	36·8	37·8	37·5	15·0
,, ,, 11 ,,	.	38·1	37·7	36·1	38·1	37·5	15·2
,, ,, 1 p.m.	.	38·8	37·8	37·0	38·2	38·0	18·2
,, ,, 3 ,,	.	38·8	38·3	38·0	38·6	38·4	17·4
,, ,, 5 ,,	.	39·0	38·6	37·9	38·4	38·5	18·2
,, ,, 7 ,,	.	38·8	39·1	39·3	38·8	39·0	18·2
,, ,, 9 ,,	.	38·6	38·9	38·4	38·0	38·5	17·4
,, ,, 11 ,,	.	38·2	38·3	37·9	37·3	37·9	18·2
,, 4th, 1 a.m.	.	37·9	37·7	37·2	38·9	37·9	17·4
,, ,, 3 ,,	.	37·8	37·7	36·9	37·9	37·6	15·4
,, ,, 5 ,,	.	37·4	37·3	37·3	36·8	37·2	15·6
,, ,, 7 ,,	.	37·7	37·8	37·3	38·6	37·9	18·2
,, ,, 9 ,,	.	38·3	37·8	37·0	38·1	37·8	18·2
,, ,, 11 ,,	.	38·7	38·7	38·7	38·2	38·6	18·6
,, ,, 1 p.m.	.	38·9	39·1	38·0	38·6	38·6	20·4
,, ,, 3 ,,	.	38·6	38·9	39·1	38·6	38·8	18·2
,, ,, 5 ,,	.	39·3	38·9	39·1	38·8	39·0	18·2
,, ,, 7 ,,	.	39·3	39·2	38·9	38·4	38·9	15·5
,, ,, 9 ,,		39·1	38·6	38·8	38·3	38·7	16·4
,, ,, 11 ,,	.	38·5	38·1	38·4	38·1	38·3	16·6

PERIOD I.—*continued.*

1903.	A.	C.	E.	D.	F.	Mean.	Room.
Apr. 5th, 1 a.m.	.	38·0	37·4	37·7	37·6	37·7	14·4
,, ,, 3 ,,	.	37·8	36·7	37·1	37·2	37·2	14·5
,, ,, 5 ,,	.	37·7	37·2	36·7	36·9	37·1	17·4
,, ,, 7 ,,	.	37·7	38·4	36·1	37·7	37·5	18·6
,, ,, 11 ,,	.	38·8	37·8	37·2	37·9	37·9	17·6
,, ,, 1 p.m.	.	39·0	37·9	38·8	38·2	38·5	17·4
,, ,, 3 ,,	.	39·4	38·1	38·1	38·3	38·5	15·5
,, ,, 5 ,,	.	39·1	38·9	39·2	38·6	39·0	15·0
,, ,, 7 ,,	.	39·2	38·7	38·4	39·1	38·9	15·5
,, ,, 9 ,,	.	38·8	38·5	38·8	38·8	38·7	.
,, ,, 11 ,,	.	38·3	37·7	37·8	37·3	37·8	.
,, 6th, 1 a.m.	.	37·9	37·6	36·9	37·6	37·5	.
,, ,, 3 ,,	.	37·4	37·3	36·6	37·3	37·2	.
,, ,, 5 ,,	.	36·9	36·7	36·0	37·4	36·8	.
,, ,, 7 ,,	.	36·9	37·7	35·8	37·7	37·0	.
,, ,, 9 ,,	.	38·6	38·2	38·0	38·2	38·3	.
,, ,, 11 ,,	.	38·9	38·6	38·4	38·3	38·6	.
,, ,, 1 p.m.	.	39·1	38·6	38·8	38·4	38·7	.
,, ,, 3 ,,	.	39·1	38·9	38·4	38·6	38·8	.
,, ,, 5 ,,	.	39·1	37·9	37·9	38·4	38·3	15·6
,, ,, 7 ,,	.	38·7	38·2	38·4	38·4	38·4	15·5
,, ,, 9 ,,	.	38·3	38·6	37·9	38·2	38·2	15·0
,, ,, 11 ,,	.	38·0	37·9	37·8	37·4	37·8	16·4
,, 7th, 1 a.m.	.	37·4	37·1	37·8	37·7	37·5	16·8
,, ,, 3 ,,	.	37·4	36·5	37·8	37·3	37·3	17·4
,, ,, 5 ,,	.	37·3	37·3	36·9	37·8	37·3	17·4
,, ,, 7 ,,	.	37·8	37·1	37·3	.	37·4	17·4
,, ,, 9 ,,	.	38·2	37·4	37·1	38·0	37·7	15·5
,, ,, 11 ,,	.	38·4	38·4	37·3	38·2	38·1	15·0
,, ,, 1 p.m.	.	38·8	38·7	38·7	38·2	38·6	15·5
,, ,, 3 ,,	.	39·0	38·3	37·8	38·3	38·4	15·0
	B.						
,, ,, 5 ,,	39·1	39·4	38·8	38·3	38·7	38·9	15·0
,, ,, 7 ,,	.	39·6	38·7	38·4	39·0	38·9	16·4
,, ,, 9 ,,	38·9	38·4	37·8	38·0	38·0	38·2	16·1
,, ,, 11 ,,	38·8	37·8	38·0	37·6	37·8	38·0	16·5
,, 8th, 1 a.m.	38·0	37·3	37·5	37·4	37·4	37·5	15·8
,, ,, 3 ,,	38·5	37·4	37·6	37·3	37·7	37·7	15·4
,, ,, 5 ,,	38·2	37·7	37·1	36·9	37·6	37·5	15·0
,, ,, 7 ,,	38·0	37·2	37·3	36·7	37·9	37·4	16·4
,, ,, 9 ,,	38·9	38·3	37·8	37·1	38·2	38·1	17·2
,, ,, 11 ,,	39·0	38·9	38·0	37·7	38·2	38·4	17·4
,, ,, 1 p.m.	38·9	38·9	38·3	37·9	38·2	38·4	15·0
,, ,, 3 ,,	39·1	39·2	39·1	39·2	38·6	39·0	16·6
,, ,, 5 ,,	39·3	39·3	38·9	39·1	38·6	39·0	17·8
,, ,, 7 ,,	39·0	38·9	38·7	38·3	38·6	38·7	17·4
,, ,, 9 ,,	38·6	38·9	38·1	38·2	38·4	38·4	18·6
,, ,, 11 ,,	38·3	37·8	37·3	37·2	37·8	37·7	.
,, 9th, 1 a.m.	38·1	37·3	36·8	37·0	37·3	37·3	.
,, ,, 3 ,,	37·3	36·7	36·7	37·1	37·0	37·0	.
,, ,, 5 ,,	37·3	37·3	36·9	36·4	37·3	37·0	.
,, ,, 7 ,,	38·0	37·7	37·7	37·4	37·7	37·7	.
,, ,, 9 ,,	39·0	38·1	38·3	37·4	38 6	38·3	.
,, ,, 11 ,,	38·8	38·2	38·3	37·6	38·4	38·3	.
,, ,, 1 p.m	39·2	39·0	38·7	38·3	38·6	38·8	18·2
,, ,, 3 ,,	39·0	38·9	38·8	38·0	38·4	38·6	16·4
,, ,, 5 ,,	.	.	.	.	.	.	.
,, ,, 7 ,,	38·9	38·8	38·3	38·1	38·2	38·5	20·0
,, ,, 9 ,,	38·2	38·0	38·9	37·7	38 0	38·2	18·3
,, ,, 11 ,,	38·4	37·8	38·1	37·1	37·7	37·8	20·6
,, 10th, 1 a.m.	37·7	37·8	37·1	37·3	37·4	37·5	21·7
,, ,, 3 ,,	37·3	37·3	38·1	37·3	37·3	37·5	22·2
,, ,, 5 ,,	37·2	37·3	36 7	36·7	37·4	37·1	22·8
,, ,, 7 ,,	37·8	36·9	37·6	37·7	37·9	37·6	22·8
,, ,, 9 ,,	38·8	38·4	37·7	37·7	38·0	38·1	20·6
,, ,, 11 ,,	38·9	38·3	38·1	38·1	38·3	38·3	21·1
,, ,, 1 p.m.	39·0	39·2	38·1	38·1	38·3	38·5	21·1

PERIOD I.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.	Room.
Apr. 10th, 3 p.m.	38·8	39·2	38·3	38·7	38·4	38·7	16·7
,, ,, 5 ,,	38·7	39·3	38·8	38·8	38·4	38·8	15·6
,, ,, 7 ,,	39·1	39·1	38·8	38·6	38·6	38·8	20·0
,, ,, 9 ,,	38·4	39·2	38·1	37·8	38·4	38·4	17·8
,, ,, 11 ,,	38·1	38·3	37·8	38·2	37·6	38·0	19·4
,, 11th, 1 a.m.	36·9	37·4	37·8	38·0	38·0	37·6	20·0
,, ,, 3 ,,	36·7	37·2	37·4	37·8	37·0	37·2	20·0
,, ,, 5 ,,	37·0	37·7	37·2	37·4	37·9	37·4	20·0
,, ,, 7 ,,	37·1	38·0	36·9	36·8	37·6	37·3	20·0
,, ,, 9 ,,	37·9	38·2	37·3	37·6	37·7	37·7	17·8
,, ,, 11 ,,	.	.	.	.	.	.	.
,, ,, 1 p.m.	38·9	38·9	38·0	38·0	38·2	38·4	19·4
,, ,, 3 ,,	38·0	38·9	38·9	38·7	38·7	38·6	21·1
,, ,, 5 ,,	38·2	39·1	38·7	38·9	38·9	38·8	21·1
,, ,, 7 ,,	38·2	38·7	38·3	39·3	38·2	38·5	20·0

(The monkeys were not allowed to sleep till 9 a.m., and no records were taken till 5 p.m. on 12th.)

PERIOD II.

Apr. 12th, 5 p.m.	37·7	38·3	37·9	38·1	37·7	37·9	20·6
,, ,, 7 ,,	38·0	38·1	37·6	37·8	37·2	37·7	20·0
,, ,, 9 ,,	38·6	38·6	38·1	38·1	37·4	38·2	20·0
,, ,, 11 ,,	38·1	38·6	38·1	38·2	37·4	38·1	20·6
,, 13th, 1 a.m.	38·3	38·6	38·1	38·2	37·8	38·2	20·6
,, ,, 3 ,,	38·1	38·2	38·2	38·1	37·4	38·0	20·6
,, ,, 5 ,,	37·9	38·7	38·0	37·4	37·2	37·8	20·6
,, ,, 7 ,,	38·5	38·3	38·3	38·1	37·1	38·1	20·6
,, ,, 9 ,,	38·1	38·0	37·4	36·6	36·1	37·2	17·8
,, ,, 11 ,,	37·8	37·8	38·3	36·4	37·0	37·3	19·4
,, ,, 1 p.m.	37·6	37·7	38·6	36·8	37·3	37·6	20·0
,, ,, 3 ,,	38·2	37·9	36·9	37·8	37·2	37·6	20·6
,, ,, 5 ,,	38·0	37·7	37·3	37·9	37·6	37·7	20·6
,, ,, 7 ,,	37·4	37·2	37·0	37·1	37·0	37·1	17·8
,, ,, 9 ,,	37·7	36·7	37·2	37·2	37·2	37·2	15·6
,, ,, 11 ,,	38·4	38·0	37·7	37·9	37·6	37·9	16·1
,, 14th, 1 a.m.	38·4	38·7	38·6	37·8	38·2	38·3	20·0
,, ,, 3 ,,	38·6	38·6	38·2	38·0	38·6	38·4	18·9
,, ,, 5 ,,	38·9	38·3	38·3	37·7	38·6	38·4	18·3
,, ,, 7 ,,	37·8	38·9	38·7	37·6	38·6	38·5	18·3
,, ,, 9 ,,	37·4	37·8	38·0	37·3	37·9	37·7	18·3
,, ,, 11 ,,	37·3	37·3	37·8	36·3	37·6	37·3	18·9
,, ,, 1 p.m.	37·2	37·3	37·4	36·7	37·6	37·2	18·9
,, ,, 3 ,,	37·4	37·4	36·9	35·7	37·6	37·0	18·9
,, ,, 5 ,,	37·6	37·7	37·4	35·8	37·8	37·3	18·9
,, ,, 7 ,,	36·9	37·8	37·6	36·3	37·1	37·1	16·7
,, ,, 9 ,,	37·6	36·9	37·4	37·4	37·4	37·3	16·7
,, ,, 11 ,,	38·0	39·0	38·7	38·6	38·0	38·5	16·7
,, 15th, 1 a.m.	38·8	38·9	38·6	38·6	38·3	38·6	18·3
,, ,, 3 ,,	38·1	38·8	38·4	38·0	38·6	38·4	18·3
,, ,, 5 ,,	.	38·7	38·6	38·3	38·4	38·5	16·1
,, ,, 7 ,,	38·6	39·1	39·1	38·1	38·7	38·7	18·3
,, ,, 9 ,,	38·9	38·9	38·6	38·3	38·0	38·5	18·3
,, ,, 11 ,,	37·9	37·2	38·0	36·6	37·8	37·5	18·3
,, ,, 1 p.m.	37·9	37·7	37·6	36·4	37·6	37·4	18·3
,, ,, 3 ,,	37·4	37·2	36·9	36·6	37·3	37·1	18·9
,, ,, 5 ,,	38·1	37·0	37·6	36·4	38·1	37·4	19·4
,, ,, 7 ,,	37·1	37·8	37·6	36·5	36·9	37·2	16·7
,, ,, 9 ,,	37·2	37·4	37·8	36·9	37·8	37·4	18·3
,, ,, 11 ,,	38·9	38·7	38·6	38·0	38·0	38·4	14·4
,, 16th, 1 a.m.	38·4	38·7	38·9	37·9	38·1	38·4	17·9
,, ,, 3 ,,	39·1	38·6	39·0	38·0	38·6	38·7	17·8
,, ,, 5 ,,	38·1	.	39·0	37·8	38·4	38·3	18·3
,, ,, 7 ,,	38·7	39 0	38·8	38·3	38·4	38·6	16·7
,, ,, 9 ,,	38·3	38·6	38·3	37·8	38·3	38·3	17·8
,, ,, 11 ,,	37·4	37·3	37·5	37·6	37·6	37·5	17·2
,, ,, 1 p.m.	38·3	37·3	37·9	37·3	37·7	37·7	18·3
,, ,, 3 ,,	37·6	36·9	37·1	37·0	37·3	37·2	18·9

PERIOD II.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.	Room.
Apr. 16th, 5 p.m.	37·1	37·0	36·8	36·5	37·8	37·0	18·9
,, ,, 7 ,,	37·1	37·1	37·7	37·2	37·3	37·3	16·7
,, ,, 9 ,,	36·9	37·9	37·7	37·1	37·8	37·5	17·8
,, ,, 11 ,,	38·7	.	38·1	38·1	37·8	38·2	13·8
,, 17th, 1 a.m.	38·9	38·8	38·3	38·2	38·1	38·5	17·8
,, ,, 3 ,,	39·2	39·0	38·8	38·4	38·1	38·7	17·8
,, ,, 5 ,,	38·7	38·9	38·2	38·0	38·1	38·4	17·8
,, ,, 7 ,,	38·7	38·7	38·3	38·4	37·9	38·4	17·8
,, ,, 9 ,,	38·9	38·1	38·9	38·8	38·1	38·6	17·8
,, ,, 11 ,,	38·3	37·3	37·6	37·3	37·9	37·7	17·8
,, ,, 1 p.m.	38·7	37·2	37·8	36·8	37·7	37·6	17·2
,, ,, 3 ,,	37·3	37·1	37·9	36·6	37·3	37·2	17·2
,, ,, 5 ,,	37·6	37·3	37·7	36·9	37·9	37·5	17·8
,, ,, 7 ,,	37·4	37·3	36·9	36·8	37·2	37·1	18·3
,, ,, 9 ,,	37·2	37·6	37·8	37·5	37·0	37·4	17·8
,, ,, 11 ,,	.	.	.	.	.	.	15·6
,, 18th, 1 a.m.	38·3	38·6	38·1	37·9	37·4	38·1	17·8
,, ,, 3 ,,	38·6	39·2	38·3	38·6	38·2	38·6	18·3
,, ,, 5 ,,	38·9	39·2	38·6	37·9	38·2	38·6	17·8
,, ,, 7 ,,	38·3	38·6	38·3	38·2	38·0	38·3	17·8
,, ,, 9 ,,	39·0	37·7	38·7	37·8	38·1	38·3	17·8
,, ,, 11 ,,	38·7	37·8	37·4	36·8	37·7	37·7	18·3
,, ,, 1 p.m.	38·9	.	.	.	.	.	18·9
,, ,, 3 ,,	37·0	37·3	37·6	36·0	37·1	37·0	18·9
,, ,, 5 ,,	36·9	37·1	37·4	36·9	38·1	37·3	18·9
,, ,, 7 ,,	37·1	37·3	37·2	36·8	36·9	37·1	18·3
,, ,, 9 ,,	36·8	37·5	37·3	37·2	36·4	37·0	18·9
,, ,, 11 ,,	38·2	38·4	38·6	38·3	38·2	38·3	15·6
,, 19th, 1 a.m.	38·8	39·2	38·7	38·6	38·2	38·7	16·7
,, ,, 3 ,,	38·4	38·8	38·7	38·2	37·9	38·4	18·3
,, ,, 5 ,,	39·0	39·0	38·3	37·2	37·9	38·3	18·9
,, ,, 7 ,,	39·2	39·3	39·1	38·4	38·2	38·8	18·9
,, ,, 9 ,,	38·9	39·0	38·3	37·2	38·1	38·7	18·9
,, ,, 11 ,,	38·4	38·5	37·4	36·4	37·9	37·7	16·7
,, ,, 1 p.m.	38·4	38·0	37·3	36·1	37·9	37·6	17·2
,, ,, 3 ,,	37·1	37·3	37·4	36·8	37·4	37·2	18·9
,, ,, 5 ,,	.	.	.	.	.	.	.
,, ,, 7 ,,	37·0	37·4	37·2	36·3	37·1	37·0	18·9
,, ,, 9 ,,	37·2	38·1	37·3	37·3	37·4	37·5	17·2
,, ,, 11 ,,	38·6	38·9	38·2	38·3	38·1	38·4	18·9
,, 20th, 1 a.m.	38·8	38·8	38·9	38·4	38·3	38·6	18·4
,, ,, 3 ,,	38·7	39·0	38·2	38·3	37·7	38·4	19·4
,, ,, 5 ,,	38·4	38·7	38·4	38·0	37·7	38·2	19·4
,, ,, 7 ,,	39·0	38·6	38·3	38·0	37·8	38·3	19·4
,, ,, 9 ,,	39·1	38·8	38·1	38·0	37·9	38·4	20·0
,, ,, 11 ,,	37·6	36·9	37·6	35·9	38·1	37·2	16·7
,, ,, 1 p.m.	37·1	37·3	37·0	35·7	38·0	37·0	17·8

PERIOD III.

Apr. 20th, 5 p.m.	38·9	38·4	38·1	36·7	38·1	38·0	19·4
,, ,, 7 ,,	38·2	38·2	38·0	37·4	38·0	38·0	17·6
,, ,, 9 ,,	38·9	39·1	38·8	38·7	38·1	38·7	18·3
,, ,, 11 ,,	38·7	39·1	38·6	38·7	37·9	38·6	15·6
,, 21st, 1 a.m.	38·2	38·7	38·3	38·9	37·8	38·4	17·8
,, ,, 3 ,,	38·6	38·6	38·6	38·6	38·3	38·5	18·3
,, ,, 5 ,,	37·4	38·4	37·9	37·4	37·7	37·8	17·8
,, ,, 7 ,,	37·9	37·9	37·6	37·2	37·3	37·6	20·0
,, ,, 9 ,,	37·7	37·3	37·3	36·7	37·7	37·3	20·0
,, ,, 10 ,,	37·3	37·3	37·6	36·4	37·3	37·2	20·0
,, ,, 12 ,,	36·4	37·2	37·0	36·9	37·6	37·0	21·1
,, ,, 1 p.m.	37·0	37·6	37·3	36·7	37·0	37·1	20·6
,, ,, 3 ,,	37·8	37·3	36·9	36·0	37·9	37·2	20·6
,, ,, 5 ,,	38·1	38·5	37·8	36·1	37·8	37·7	20·0
,, ,, 7 ,,	38·2	38·0	37·7	37·2	37·2	37·7	16·7
,, ,, 9 ,,	38·6	38·2	37·7	37·7	37·7	38·0	18·3
,, ,, 11 ,,	38·4	38·3	38·6	38·1	38·3	38·3	15·6

PERIOD III.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.	Room.
Apr. 22nd, 1 a.m.	38·0	38·9	38·3	38·7	38·2	38·4	18·9
,, ,, 3 ,,	38·9	39·3	38·8	38·6	38·0	38·7	20·0
,, ,, 5 ,,	37·9	38 6	38·3	37·4	37·3	37·9	19·4
,, ,, 11 ,,	38·0	37·0	37·0	36·6	37·0	37·1	20·0
,, ,, 1 p.m.	36·6	37·0	36·8	36·2	37·1	36·7	16·7
,, ,, 3 ,,	36·8	37·1	36·7	36·9	36·6	36·8	18·9
,, ,, 5 ,,	38·5	37·4	38·1	37·7	37·7	37·9	17·8
,, ,, 7 ,,	38·8	38·3	38·8	38·1	38·0	38·4	18·9
,, ,, 9 ,,	38·6	38·8	38·7	38·2	38·2	38·5	18·9
,, ,, 11 ,,	38·8	39·3	38·6	38·9	38·0	38·7	18·9
,, 23rd, 1 a.m.	38·5	38·7	38·6	39·1	38·1	38·6	19·4
,, ,, 5 ,,	37·9	38·0	38·0	37·6	37·3	37·8	18·9
,, ,, 7 ,,	38·5	36 8	37 2	36·8	37·3	37·4	18·9
,, ,, 9 ,,	37·2	36·9	37·3	36·9	37·8	37·2	19·4
,, ,, 11 ,,	36·9	37·0	36·7	36·3	37·6	36·9	20·0
,, ,, 1 p.m.	36·8	36·7	36·8	36·2	37·3	36·8	20·6
,, ,, 3 ,,	37·3	37·0	36·8	35·7	37·0	36·6	20·0
,, ,, 5 ,,	38·9	38·9	38·6	36·6	38·3	38·3	19·4
,, ,, 7 ,,	38·8	38·4	38·1	37·7	38·1	38·2	19·4
,, ,, 9 ,,	38·6	39·2	38·1	37·9	38·2	38·2	20·0
,, ,, 11 ,,	38·5	39·3	38·1	38·0	38·2	38·4	19·4
,, 24th, 1 a.m.	38·6	38·9	38·3	38·1	38·3	38·5	18·9
,, ,, 3 ,,	38·9	39·2	38·6	38·1	38·3	38·8	18 9
,, ,, 5 ,,	38·1	37·8	38·0	37·8	37·6	38·7	19·4
,, ,, 7 ,,	37·7	37·3	37·8	37·2	37·6	37·5	18·9
,, ,, 9 ,,	37·1	37·3	37·3	37·1	37·4	37·2	20·6
,, ,, 11 ,,	37·0	37·0	37·1	36·2	37·8	37·0	19·4
,, ,, 1 p.m.	36·7	36·8	37·4	35·8	37·3	36·8	20·0
,, ,, 3 ,,	36·9	37·4	38·3	35·9	37·0	37·1	20·6
,, ,, 5 ,,	38·6	38·1	38·6	37·6	38·0	38·2	20·6
,, ,, 7 ,,	38·4	38·3	38·2	37·2	38·2	38·1	17·8
,, ,, 9 ,,	38·5	38·7	38·3	37·8	37·9	38·2	19·4
,, ,, 11 ,,	38·6	38·3	37·9	38·3	37·9	38·2	18·3
,, 25th, 1 a.m.	38·8	38·9	38·3	38·4	38·4	38·6	18·9
,, ,, 3 ,,	38·5	39·3	38·6	38·3	38·1	38·6	19·4
,, ,, 5 ,,	37·4	37·9	37·4	37·7	37·3	37·5	20·0
,, ,, 7 ,,	37·2	37·7	37·7	37·4	37·5	37·5	20·6
,, ,, 9 ,,	37·0	37·3	37·6	37·1	37·5	37·3	21·1
,, ,, 11 ,,	36 8	36·8	37·2	37·0	37·6	37·1	21·1
,, ,, 1 p.m.	36·9	37·3	37·3	37·1	37·6	37·2	21·1
,, ,, 3 ,,	37·2	37·7	37·0	37·3	37·7	37·4	20·6
,, ,, 5 ,,	38·0	38·3	38·2	38·0	38·4	38·2	21·1
,, ,, 7 ,,	38·8	38·9	38·7	38·0	38·7	38·6	20·6
,, ,, 9 ,,	38·5	39·1	37·9	38·7	38·3	38·5	20·6
,, ,, 11 ,,	38·7	38·8	38·3	38·8	38·2	38·6	21·1
,, 26th, 1 a.m.	38·9	38·6	38·8	38·7	38·4	38·7	20·6
,, ,, 3 ,,	38·9	38·6	38·2	38·1	38·1	38·4	20·0

PERIOD IV.

Apr. 26th, 5 a.m.	37·6	37·6	37·1	37·2	37·3	37·4	21·1
,, ,, 7 ,,	37·1	37·4	37·0	36·9	37·2	37·1	21·1
,, ,, 11 ,,	37·1	37·2	37·1	36·9	37·3	37·1	15·6
,, ,, 1 p.m.	37·0	37·2	37·2	36·8	37·6	37·2	20·0
,, ,, 3 ,,	37·4	37·4	37·7	37·4	37·7	37·5	21·1
,, ,, 7 ,,	38·6	37·9	38·0	37·0	37·8	37·9	17·8
,, ,, 9 ,,	38·9	38·4	37·8	36·6	37·2	37·8	17·8
,, ,, 11 ,,	38·5	37·8	37·8	36·9	37·7	37·7	18·3
,, 27th, 1 a.m.	38·7	38·2	37·8	37·6	37·6	38·0	18·3
,, ,, 3 ,,	38·2	38·3	37·9	37·6	37·9	38·0	18·9
,, ,, 5 ,,	37·1	38·0	37·3	37·8	37·8	37·6	18·3
,, ,, 7 ,,	37·8	37·6	37·8	37·8	38·0	37·8	18·3
,, ,, 9 ,,	38·9	38·4	38·4	38·0	38·2	38·4	18·3
,, ,, 11 ,,	38·6	38·2	38·8	37·8	38·3	38·3	18·3
,, ,, 1 p.m.	38·7	38·4	38·6	37·2	37·8	38·1	18·3
,, ,, 3 ,,	38·0	38·1	38·1	37·0	38·1	37·9	18·3
,, ,, 5 ,,	38·4	38·3	38·1	36·8	37·9	37·9	18·3

PERIOD IV.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.	Room.
Apr. 27th, 7 p.m.	38·6	38·4	38·3	37·0	38·2	38·1	16·7
,, ,, 9 ,,	38·5	37·2	37·4	37·1	37·2	37·5	17·2
,, ,, 11 ,,	38·0	37·9	37·3	37·0	37·3	37·5	16·7
,, 28th, 1 a.m.	37·8	37·6	37·8	37·3	37·9	37·7	17·8
,, ,, 3 ,,	36·7	37·4	37·4	36·9	37·3	37·1	18·9
,, ,, 5 ,,	36·6	36·9	36·8	37·9	36·3	36·9	18·9
,, ,, 7 ,,	36·8	36·7	37·6	37·4	36·6	37·0	18·9
,, ,, 9 ,,	37 9	37·8	38·7	37·9	38·2	38·1	16·7
,, ,, 11 ,,	38·0	38·3	38·6	37·9	.	38·7	19·4
,, ,, 1 p.m.	38·0	37·9	38·0	37·1	38·2	37·8	18·9
,, ,, 5 ,,	38·7	38·4	38·6	37·3	38·0	38·2	18·9
,, ,, 7 ,,	38·7	38·3	38·1	37·1	38·1	38·1	16·7
,, ,, 9 ,,	37·7	37·6	37·8	37·3	37·3	37·5	16·1
,, ,, 11 ,,	36·9	38·0	37·1	37·8	37·0	37·4	17·8
,, 29th, 1 a.m.	38·2	36·9	36·8	36·6	36·8	37·1	18·9
,, ,, 3 ,,	37 3	37·7	37·1	36·9	37·3	37·3	19·4
,, ,, 5 ,,	37·0	37·3	37·3	37·5	37·1	37·2	19·4
,, ,, 7 ,,	37·8	37·6	37·6	36·1	37·3	37·3	18·9
,, ,, 11 ,,	37·4	38·0	38·0	36·9	38·4	37·7	18·9
,, ,, 1 p.m.	38·7	38·9	38·7	38·2	38·3	38·6	19·4
,, ,, 3 ,,	38·1	38·4	38·2	37·8	38·2	38·1	17·2
,, ,, 5 ,,	38·4	38·3	38·7	37·9	38·3	38·3	18·3
,, ,, 7 ,,	37·9	.	38·6	37·9	38·4	38·2	18·3
,, ,, 9 ,,	39·1	38·3	37·8	36·4	37·4	37·8	16·7
,, ,, 11 ,,	38·8	38·0	37·9	36·9	37·1	37·7	18·9
,, 30th, 1 a.m.	38·6	38·3	37·3	36·8	37·4	37·7	19·4
,, ,, 3 ,,	37·7	37·0	37·4	37·6	37·8	37·5	19·4
,, ,, 5 ,,	37·6	37·4	37·9	37·0	37·8	37·5	20·0
,, ,, 7 ,,	38·7	37·8	38·0	37·0	37·3	37·8	20·0
,, ,, 9 ,,	37·8	38·4	38·7	37·0	37·9	38·0	16·7
,, ,, 11 ,,	37·9	38·1	38·2	37·8	38·3	38·1	18·3
,, ,, 1 p.m.	38·3	38·6	38·4	37·4	38·1	38·2	18·3
,, ,, 3 ,,	38·7	38·2	38·4	37·4	38·2	38·2	16·7
,, ,, 5 ,,	38·4	38·3	38·2	36·7	38·3	38·0	16·7
,, ,, 7 ,,	.	.	.	.	.	.	.
,, ,, 9 ,,	38·3	38·3	38·3	36·7	38·6	38·0	20·0
,, ,, 11 ,,	38·6	37·9	37·3	37·0	38·3	37·8	20·0
May 1st, 1 a.m.	38·8	38·2	38·0	37·8	38·3	38·2	20·0
,, ,, 3 ,,	37·4	36·9	37·8	37·6	37·9	37·5	20·0
,, ,, 5 ,,	38·2	37·3	37·4	37·2	37·6	37·5	20·0
,, ,, 7 ,,	37·8	36·8	37·7	36·9	37·8	37·4	20·0
,, ,, 9 ,,	.	.	.	.	.	.	.
,, ,, 11 ,,	38·3	37·7	38·8	37·6	38·7	38·2	16·7
,, ,, 1 p.m.	38·0	38·2	38·2	38·2	38·0	38·1	18·3
,, ,, 3 ,,	38·3	38·3	38·2	37·8	38·0	38 1	17·8
,, ,, 5 ,,	38·2	38·0	38·7	37·2	38·1	38·0	17·8
,, ,, 7 ,,	38·1	37·6	37·8	36·9	37·9	37·7	16·7
,, ,, 9 ,,	39·4	38·6	38·4	37·7	37·8	38·4	18·9
,, ,, 11 ,,	38·9	37·8	38·3	37·7	38·2	38·2	18·9
,, 2nd, 1 a.m.	39·3	38·4	38·1	39·3	37·8	38·6	20·0
,, ,, 3 ,,	39·2	38·3	38·4	38·8	38·3	38·6	20·6
,, ,, 5 ,,	38·6	37·7	37·4	38·4	38·3	38·1	20·0
,, ,, 7 ,,	38·7	38·7	38·4	37·6	38·9	38·5	20·0

PERIOD V.

May 2nd, 11 a.m.	38·8	38·4	38·9	37·7	38·9	38·5	17·8
,, ,, 1 p.m.	39·1	38·9	38·8	39·2	38 6	38·9	17·8
,, ,, 3 ,,	38·4	37·6	37·7	38·1	38 2	38·0	15·6
,, ,, 5 ,,	38·7	38·0	38·3	38·3	38·2	38·3	17·8
,, ,, 7 ,,	38·7	38·3	38·4	38·7	38·4	38·5	18·3
,, ,, 9 ,,	38·4	38·9	38·7	37·6	37·9	38·3	18·3
,, ,, 11 ,,	38·9	39·0	38·4	38·1	37·8	38·6	18·9
,, 3rd, 1 a.m.	38·4	38·4	38·1	37·7	37·9	38·1	18·3
,, ,, 3 ,,	38·4	38·4	37·9	38·4	37·9	38·2	18·9
,, ,, 5 ,,	37·7	37·9	38·1	37·1	37·4	37·6	18·3
,, ,, 7 ,,	37·8	38·2	38·4	36·9	37·3	37·7	18 3

PERIOD V.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.	Room.
May 4th, 1 a.m.	39·2	39·1	38·7	38·6	38·0	38·7	18·3
,, ,, 3 ,,	38·9	38·8	38·4	38·1	37·8	38 4	17·8
,, ,, 5 ,,	38·7	38·0	38·7	38·0	37·8	38·2	17·8
,, ,, 7 ,,	38·9	38·1	38·2	38·4	38·0	38·3	17·2
,, ,, 9 ,,	38·2	38·0	38·1	37·6	37·4	37·9	17·8
,, ,, 11 ,,	38·7	37·9	38·7	36·6	37·6	37·9	17·2
,, ,, 1 p.m.	38·6	38·4	38·1	36·9	37·1	37·8	17·8
,, ,, 3 ,,	38·4	38·3	38·9	38·3	37·9	38·4	17·8
,, ,, 5 ,,	39·1	37·9	38·3	37·2	38·4	38·2	17·8
,, ,, 7 ,,	38·3	38·6	38·0	36·8	39·3	38·2	18·3
,, ,, 9 ,,	38·8	38·6	38·7	37·2	38·3	38·3	18·3
,, ,, 11 ,,	39·1	38·9	38·4	37·1	38·2	38·5	18·3
,, 5th, 1 a.m.	37·9	38·1	38·1	36·8	38·0	37·8	18·3
,, ,, 3 ,,	38·8	38·4	38·6	37·7	38·1	38·3	18·3
,, ,, 5 ,,	37·9	38·3	38·1	37 6	38·0	38·0	17·8
,, ,, 7 ,,	37·8	37·9	38·3	37·6	38·0	37·9	17·8
,, ,, 11 ,,	38·8	38·9	38·6	38·0	37·9	38·4	18·3
,, ,, 1 p.m.	38·6	39·2	37·9	37·3	38·2	38·2	18·3
,, ,, 3 ,,	38·8	39·0	38·5	38·0	38·3	38·5	18·3
,, ,, 5 ,,	38·9	39·1	38·4	38·1	38·4	38·6	18·9
,, ,, 7 ,,	39·1	38·8	38·6	37·9	39·1	38·7	18·9
,, ,, 9 ,,	38·3	38·4	37·9	37·9	38·7	38·2	19·4
,, ,, 11 ,,	38·2	38·6	37·8	38·1	37 9	38·1	18·3
,, 6th, 1 a.m.	38·2	39·0	37·9	38·2	37·7	38·2	18·3
,, ,, 3 ,,	37·8	38·0	37·3	37·7	37·8	37·7	20·0
,, ,, 5 ,,	37·6	37·4	37·9	37·3	37·3	37·5	18·9
,, ,, 7 ,,	38·4	37·9	38·2	37·1	38·2	38·0	18·3
,, ,, 9 ,,	37·3	38·4	36·9	38·0	38·1	37·7	18·9
,, ,, 11 ,,	37·2	37·3	38·4	38·4	37·8	37·8	18·9
,, ,, 1 p.m.	38·4	38·9	38·8	38·7	38·0	38·6	19·4
,, ,, 3 ,,	39·3	39·1	38·9	38 8	38·1	38·8	18·9
,, ,, 5 ,,	38·8	39·3	38·7	37·8	38·8	38·7	18·6
,, ,, 7 ,,	39·4	38·8	38·6	38·8	38·2	38·8	18·3
,, ,, 9 ,,	37·9	37·8	37·2	37·4	39·1	37·9	18·3
,, ,, 11 ,,	.	39·0	37·9	37·3	38·0	38·5	.
,, 7th, 1 a.m.	38·8	38·7	37·9	37·3	37·8	38·1	17·8
,, ,, 3 ,,	37·7	38·6	37·8	37·0	37·4	37·7	18·3
,, ,, 5 ,,	37·9	38 6	37·7	37·3	37·8	37·9	18·3
,, ,, 7 ,,	37·9	38·7	.	.	.	.	18·3
,, ,, 9 ,,	38·7	.	38·4	37·9	38·2	38·3	17·2
,, ,, 11 ,,	38·0	37·9	37·4	36 9	37·2	37·5	17·8
,, ,, 1 p.m.	37·0	37·7	37·9	37·7	36·9	37·4	18·3
,, ,, 3 ,,	36·9	37·7	38·7	36·7	36·8	37·4	18·9
,, ,, 5 ,,	38·7	37·4	37·8	38·1	38·0	38·0	18·9
,, ,, 7 ,,	39·1	38·5	36·9	38·5	38·1	38·2	19·4
,, ,, 9 ,,	37·9	38·7	36·7	37·8	38·3	37·9	18·9
,, ,, 11 ,,	39·1	38·6	38·7	38·0	38·1	38·9	19·4
,, 8th, 1 a.m.	38·6	38·4	38·7	38 0	37·8	38·3	18·9
,, ,, 3 ,,	38·3	38·1	37·8	37·6	37·6	37·9	17·8
,, ,, 5 ,,	38·0	38·2	37·9	37·3	37·6	37·8	18·9
,, ,, 7 ,,	39·1	38·8	37·8	36·9	37·3	38·0	18·3
,, ,, 9 ,,	37·9	37·9	37·3	36·8	36·9	37·4	18·3
,, ,, 11 ,,	38·2	37·3	38·0	36·9	37·9	37·7	18·3
,, ,, 1 p.m.	37·8	36·8	36·9	37·9	38·6	37·6	18·9
,, ,, 3 ,,	37·4	38·0	38·4	38·2	38·8	38·2	18·3
,, ,, 5 ,,	38·5	38·8	38·9	38·6	37·9	38·5	18·3
,, ,, 7 ,,	39·0	38·5	38·6	36·5	38·0	38·1	18·3
,, ,, 9 ,,	37·9	37·8	37·3	36·3	37·8	37·4	18·9

PERIOD VI.

1903.	B.	C.	E.	D.	F.	Mean.
Fore-period.						
May 26th, 1 p.m. .	38·9	38·4	37·9	37·9	37·8	38·2
,, ,, 3 ,, .	39·6	38·8	38·4	37·7	38·1	38·5
,, ,, 5 ,, .	39·7	39·1	38·6	37·8	38·0	38·6
,, ,, 7 ,, .	39·3	39·4	38·6	38·1	38·1	38·7
,, ,, 9 ,, .	38·4	38·9	39·3	38·1	37·9	38·5
,, ,, 11 ,, .	39·4	38·8	38·8	37·8	38·4	38·6
,, 27th, 1 a.m. .	38·1	38·0	38·8	37·1	38·3	38·1
,, ,, 3 ,, .	37·0	38·1	37·8	36·9	37·7	37·5
,, ,, 5 ,, .	37·9	37·8	38·1	36·9	37·6	37·7
,, ,, 7 ,, .	38·2	38·1	37·8	36·4	36·9	37·5
,, ,, 9 ,, .	38·5	38·3	37·8	36·0	37·4	37·6
,, ,, 11 ,, .	38·9	38·6	38·6	37·6	37·6	38·3
,, ,, 1 p.m. .	38·7	38·8	38·8	38·0	37·3	38·3
,, ,, 3 ,, .	38·8	39·1	38·4	38·3	38·0	38·5
,, ,, 5 ,, .	38·9	39·0	38·1	38·7	37·9	38·5
,, ,, 7 ,, .	39·2	39·1	38·6	38·0	37·6	38·5
,, ,, 9 ,, .	39·1	38·8	39·4	38·7	37·8	38·8
,, ,, 11 ,, .	38·7	38·4	38·3	37·6	37·6	38·1
,, 28th, 1 a.m. .	38·1	37·8	38·1	37·0	36·8	37·6
,, ,, 3 ,, .	37·9	37·6	37·6	35·9	37·6	37·3
,, ,, 5 ,, .	38·6	38·1	37·9	35·9	37·7	37·6
,, ,, 7 ,, .	38·7	38·2	37·8	36·7	38·0	37·9
,, ,, 9 ,, .	38·7	38·4	38·2	36·8	37·1	37·8
,, ,, 11 ,, .	38·9	38·8	38·2	37·1	37·3	38·1
,, ,, 1 p.m. .	38·6	38·6	38·7	38·0	37·7	38·3
,, ,, 3 ,, .	39·0	39·1	38·4	37·9	38·2	38·5
,, ,, 5 ,, .	39·1	38·9	.	38·4	38·4	38·7
,, ,, 7 ,, .	39·4	39·0	38·7	38·2	38·5	38·8
,, ,, 9 ,, .	38·9	38·0	38·6	37·3	37·8	38·1
,, ,, 11 ,, .	38·4	38·4	38·7	37·8	37·9	38·2
,, 29th, 1 a.m. .	38·0	38·1	38·2	37·2	37·6	37·8
,, ,, 3 ,, .	38·0	37·9	37 8	37·2	37·2	37·6
,, ,, 5 ,, .	37·8	37·4	38·0	36 9	36·6	37·3
,, ,, 7 ,, .	38·0	38·6	37·8	38·0	38·0	38·1
,, ,, 9 ,, .	38·7	38·7	38·3	37·7	37·8	38·2
,, ,, 11 ,, .	38·3	38·0	38 2	37·6	38·0	38·0
,, ,, 1 p.m. .	39·3	37·3	37·4	37·9	38·7	38·1
,, ,, 3 ,, .	38·3	38·3	38·6	37·8	38·6	38·3
,, ,, 5 ,, .	39·2	39·1	38·7	38·1	38·2	38·7
,, ,, 7 ,, .	39·1	38·9	39·2	38·7	38·7	38·9
Starvation period.						
May 29th, 9 p.m. .	39·2	38·7	38·4	38·0	38·2	38·5
,, ,, 11 ,, .	39·2	38·0	38·7	37·0	37·6	38·1
,, 30th, 1 a.m. .	37·7	38·8	38·4	37·0	37·2	37·8
,, ,, 3 ,, .	38·2	38·4	38·4	36·0	37·0	37·6
,, ,, 5 ,, .	39·0	38·5	38·0	36·0	36·8	37·6
,, ,, 7 ,, .	39·0	38·4	38·3	37·0	37·2	38·0
,, ,, 9 ,, .	39·4	38·6	38·0	37·0	37·4	38·1
,, ,, 11 ,, .	38·9	38·3	38·2	37·4	38·2	38·2
,, ,, 1 p.m. .	39·0	39·4	38·6	37·3	38·3	38·5
,, ,, 3 ,, .	39·3	39·6	38·2	37·7	38·2	38·6
,, ,, 5 ,, .	38·8	39·2	38·2	38·0	38·1	38·5
,, ,, 7 ,, .	.	.	.	.	38·2	.
,, ,, 9 ,, .	38·3	37·8	37·9	36·3	37·4	37·1
,, ,, 11 ,, .	38·3	37·7	37·1	36·2	37·6	37·4
,, 31st, 1 a.m. .	38·2	38·1	37·8	35·7	37·1	37·4
,, ,, 3 ,, .	38·2	37·4	37·4	36·8	37·4	37·4
,, ,, 5 ,, .	38·1	37·8	37·9	36·7	37·8	37·7
,, ,, 7 ,, .	37·7	37·8	37·6	36·8	37·0	37·4
,, ,, 9 ,, .	37·9	36·8	37·1	.	37·3	37·3
,, ,, 11 ,, .	38·2	37·8	37·0	38·4	37·6	37·8
,, ,, 1 p.m. .	38·6	38·0	38·0	37·7	37·7	38·0
,, ,, 3 ,, .	38·6	38·6	37·7	37·2	37·9	38·0
,, ,, 5 ,, .	38·4	38·7	37·8	37·1	37·8	38·0
,, ,, 7 ,, .	37·2	37·6	38·2	37·0	37·3	37·5

PERIOD VI.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.
Starvation period.—continued.						
May 31st, 9 p m .	37·7	37·4	38·4	36·7	37·1	37·5
,, ,, 11 ,, .	37·1	37·2	38·1	36·2	36·9	37·1
June 1st, 1 a.m. .	37·1	37·2	37·2	36·3	37·7	37·1
,, ,, 3 ,, .	36·9	37·2	37·8	36·0	38·0	37·2
,, ,, 5 ,, .	37·0	36·9	38·1	36·1	37·9	37·2
,, ,, 7 ,, .	37·0	37·1	38·0	36·0	38·0	37·2
,, ,, 9 ,, .	37·4	37·9	37·7	37·7	37·9	37·7
,, ,, 11 ,, .	38·1	38·1	38·0	38·7	37·7	38·3
,, ,, 1 p.m. .	37·7	38·1	38·6	38·6	37·3	38·1
,, ,, 3 ,, .	38·7	38·4	37·9	38·6	37·7	38·3
,, ,, 5 ,, .	38·4	38·4	38·2	38·7	37·8	38·2
After-period.						
June 1st, 7 p.m. .	39·0	38·2	38·4	38·9	38·6	38·6
,, ,, 9 ,, .	38·3	37·8	37·9	38·1	37·7	38·0
,, ,, 11 ,, .	36·9	36·9	38·3	37·1	38·2	37·5
,, 2nd, 1 a.m. .	36·4	36·7	37·8	37·2	37·9	37·2
,, ,, 3 ,, .	36·6	37·1	37·9	37·2	37·6	37·3
,, ,, 5 ,, .	36·7	36·9	37·7	37·2	37·7	37·2
,, ,, 7 ,, .	37·8	37·8	37·9	37·6	37·4	37·7
,, ,, 9 ,, .	37·7	38·0	37·2	37·4	36·7	37·4
,, ,, 11 ,, .	37·5	37·7	37·9	38·2	36·8	37·6
,, ,, 1 p.m. .	38·2	37·7	37·7	39·7	37·8	38·2
,, ,, 3 ,, .	.	.	.	.	.	.

PERIOD VI.—*continued.*

1903.	B.	C.	E.	D.	F.	Mean.
After-period—contd.						
June 2nd, 5 p.m. .	39·4	38·2	38·3	39·2	38·3	38·7
,, ,, 7 ,, .	38·9	38·3	38·2	38·3	38·0	38·3
,, ,, 9 ,, .	37·8	36·9	38·1	38·1	38·6	37·9
,, ,, 11 ,, .	37·2	37·4	37·8	37·9	37·9	37·6
,, 3rd, 1 a.m. .	37·3	37·7	38·2	37·8	37·3	37·7
,, ,, 3 ,, .	37·4	37·6	37·9	37·7	37·4	37·6
,, ,, 5 ,, .	37·3	37·7	38·0	37·2	37·6	37·6
,, ,, 7 ,, .	37·2	37·6	37·7	36·9	38·0	37·5
,, ,, 9 ,, .	37·2	37·4	37·4	36·3	37·6	37·2
,, ,, 11 ,, .	37·8	.	38·3	37·7	39·0	38·2
,, ,, 1 p.m. .	39·0	38·6	39·2	38·2	38·9	38·8
,, ,, 3 ,, .	38·9	39·0	38·4	38·6	38·7	38·3
,, ,, 5 ,, .	39·4	38·8	38·3	38·6	38·6	38·7
,, ,, 7 ,, .	39·2	38·7	38·9	38·4	38·8	38·8
,, ,, 9 ,, .	37·9	37·9	38·6	37·9	38·7	38·2
,, ,, 11 ,, .	37·6	37·1	38·2	36·0	38·8	37·5
,, 4th, 1 a.m. .	37·3	36·9	38·0	36·4	38·6	37·4
,, ,, 3 ,, .	37·2	36·9	37·8	36·2	38·1	37·0
,, ,, 5 ,, .	37·3	37·1	37·1	35·6	38·4	37·1
,, ,, 7 ,, .	38·0	37·3	37·6	36·2	37·6	37·3
,, ,, 9 ,, .	38·7	38·1	37·8	35·6	37·8	37·6
,, ,, 11 ,, .	38·8	38·2	38·3	36·9	38·6	38·2
,, ,, 1 p.m. .	39·2	36·9	38·2	37·7	38·2	38·0
,, ,, 3 ,, .	39·3	38·3	38·9	38·0	38·4	38·6
,, ,, 5 ,, .	38·8	38·9	38·3	38·1	38·8	38·6

PERIOD I.

This extended from 1 p.m. on March 23rd to 7 p.m. on April 11th, 1903—nineteen days—but all the monkeys are not included till 1 p.m. on March 30th (see Table, p. 79). The monkeys were tied up at 9 p.m. and the lights put out. They were released at 9 a.m. The period of rest was thus from 9 p.m. till 9 a.m., and the period of activity from 9 a.m. till 9 p.m. They went to sleep almost immediately on being tied up, and continued to rest till about 7 a.m., when they began to show signs of activity, though some were often asleep until set free at 9 a.m. They had regular meals at 9 a.m. and 6 p.m., but there was always a supply of nuts, etc., in the room, and they fed intermittently during the whole day.

The continuous line in figs. 1–5, pp. 86–88, shows the mean diurnal curve in each monkey from 5 p.m. on April 7th till 5 p.m. on April 11th, and in the coloured chart I. in the Appendix the curves of the three macacus monkeys B, C, D, are given from April 4th onwards without interruption. In B the mean minimal temperature was recorded at 5 a.m., in C at 3 a.m., in D at 5 a.m., in E at 5 a.m., and in F at 3 a.m., while the maximal in B was found to be at 1 p.m., in C at 5 p.m., in D at 7 p.m., in E at 7 p.m., and in F at 5 p.m. In B the mean range was 1·58° (37·42 to 39), in C 1·73° (37·47 to 39·2), in D 1·84° (36·72 to 38·56), in E 1·47° (37·25 to 38·72), and in F 1·11° (37·42 to 38·53). The greatest range was found in the macacus monkeys, and

of these it was greatest in D, a very old specimen, and not, as one would have expected, in C, which was immature. In the curve compounded from the mean of all five monkeys (fig. 6, p. 88), the minimal point is reached at 5 a.m., the maximal at 5 p.m., and the range is 1·62° (37·25 to 38·87). In this compounded curve the rise is most rapid from 7 to 9 a.m.; from 9 a.m. till 5 p.m. it is very regular, but slower; from 7 p.m. to 1 a.m. the fall is most rapid; it is very slow between 1 a.m. and 5 a.m., after which it again begins to rise. There are no secondary curves. In monkey B* (red curve in chart I.), the range for the whole period was 2·6° (36·7 at 3 a.m. April 11th to 39·3 at 5 p.m. April 8th), in C (blue) 2·9° (36·7 at 3 a.m. on April 9th to 39·6 at 7 p.m. on April 7th), in D (green) 3·4° (35·8 at 7 a.m. April 6th to 39·2 at 5 p.m. April 5th), in E (not represented in chart I.) 2·7° (36·5 at 3 a.m. April 7th to 39·2 at 7 p.m. April 4th), in F (not in chart I.) 2·3° (36·8 at 5 a.m. April 4th to 39·1 at 7 p.m. April 5th), and in the mean of all five 2° (37·0 at 3 and 5 a.m. April 9th to 39·0 at 3 and 5 p.m. April 8th). The greatest range in any single period of twenty-four hours was in B (red) 2·4° (36·7 at 3 a.m. April 11th to 39·1 at 7 p.m. April 10th), in C (blue) 2·6° (36·7 at 3 a.m. April 9th to 39·3 at 5 p.m. April 8th), in D (green) 3·4° (35·8 at 7 a.m. April 6th to 39·2 at 5 p.m. April 5th), in E 2·5° (36·7 at 3 a.m. April 5th to 39·2 at 7 p.m. April 4th), in F 2·0° (36·8 at 5 a.m April 4th to 38·8 at 5 p.m. April 3rd), and in the mean of all five 2° (37·0 at 3 and 5 a.m. April 9th to 39·0 at 3 and 5 p.m. April 8th).

PERIOD II.

This extended from 5 p.m. on April 12th till 5 p.m. April 20th. During this period the conditions were completely reversed; the resting period was now from 9 a.m. to 9 p.m., and the active period from 9 p.m. to 9 a.m. The monkeys were tied up at 9 a.m., the room darkened and silence ensured; at 9 p.m. they were set free, and at the same time the room was brightly illuminated by a powerful electric light. During the active period under the reversed conditions much of the observers' time was spent with them, but beyond this no artificial means were employed to make them adopt the new routine. They were now fed at 6 a.m. and 9 p.m. They were not allowed to rest on the night preceding this period, so that they might sleep during the succeeding day, and no temperature readings were taken from 7 p.m. April 11th till 5 p.m. April 12th.

The result was a complete reversal of the diurnal variation curves, as may be seen in figs. 1–6,† pp. 86–88, and in chart I. By the third day the rhythm is well established, and it is maintained to the end of the period, while the regularity of the curves compares favourably with that of Period I.

* See p. 77 for description of this and other monkeys, C, D, E, F.

† The diurnal curve for this period is represented by the interrupted line.

In B the minimal temperature in this mean curve is found at 7 p.m., in C at 3 p.m., in D at 3 p.m., in E at 1 p.m, in F at 7 p.m., and in the average curve obtained from all five at 3 p.m. The maximal was reached in B at 3 a.m. and 7 a.m. (two maxima), in C at 7 a.m., in D at 7 a.m., in E at 1 a.m. and 3 a.m. (two maxima), in F at 3 a.m., and in the mean of all five at 7 a.m. There is thus a greater variation in the time at which the maximal and minimal points are reached than in the normal period. In B the mean range was 1·35° (37·25 to 38·6), in C 1·51° (37·3 to 38·81), in D 1·66° (36·54 to 38·20), in E 1·37° (37·24 to 38·61), in F 1·05° (37·09 to 38·14), and for the average of all five 1·27° (37·19 to 38·46). In B the range for the whole period was 2·4° (36·8 at 9 p.m. April 18th to 39·2 at 3 a.m. on 17th and at 7 a.m. on 19th), in C 2·6° (36·7 at 9 p.m. April 13th to 39·3 at 7 a.m. April 19th), in D 3·1° (35·7 at 1 p.m. April 20th to 38·8 at 9 a.m. April 17th), in E 2·3° (36·8 at 5 p.m. on 16th to 39·1 at 7 a.m. on 15th and 19th), in F 2·6° (36·1 at 9 a.m. on 13th to 38·7 at 7 a.m. on 15th), and in the mean of all five 1·8° (37·0 on six occasions to 38·8 at 7 a.m. on 19th). The greatest range in any single day of twenty-four hours was in B 2·4° (36·8 at 9 p.m. on 18th to 39·2 at 7 a.m. on 19th), in C 2·4° (36·7 at 9 p.m. on 14th to 39·1 at 7 a.m. on 15th), in D 2·9° (35·7 at 3 p.m. on 14th to 38·6 at 1 a.m. on 15th), in E 2·2° (36·9 at 3 p.m. to 39·1 at 7 a.m. on 15th), in F 2·5° (36·1 at 9 a.m. on 13th to 38·6 at 3 a.m. on 14th), and in the average of all five 1·8° (37·0 at 9 p.m. on 18th to 38·8 at 7 a.m. on 19th).

PERIOD III.

Extended from 5 p.m. on April 20th till 3 a.m. on April 26th. It was a slight modification of the conditions obtaining in Period II. The monkeys were now tied up and the room darkened at 3 a.m., and liberated at 3 p.m., when daylight was admitted; the resting and active periods were therefore 3 a.m. to 3 p.m. and 3 p.m. to 3 a.m. respectively. They were fed at midnight and at 3 p.m. The curves gradually assumed a swing corresponding to the changed conditions. See figs. 1–6, pp. 86–88 (crossed line), and chart I. In the chart the gradual retardation of the maxima and minima is evident in the case of each of the three (B,. C, D) whose curves are represented. In this period the mean minimal temperature was recorded in B at 1 p.m., in C at 11 a.m., in D at 1 p.m., in E at 11 a.m., in F at 1 p.m. and 3 p.m., and in the compounded curve from all five at 1 p.m. The maximum in B was reached at 3 a.m., in C at 3 a.m., in D at 1 a.m., in E at 3 a.m., in F at 1 a.m., and in the compounded curve at 3 a.m. The swing during this period was more regular than in Period II., especially in the early part of the latter, as is revealed by the fact that there are fewer secondary curves thrown in on the primary curve. A glance at figs. 1–6, pp. 86–88, will show that of the three mean curves that of Period II. (interrupted line), is the most irregular and contains the greatest number of secondary waves. In B the mean range was 1·93° (36·83 to 38·76), in C 1·95° (37·05 to 39·00), in D 2·18° (36·47

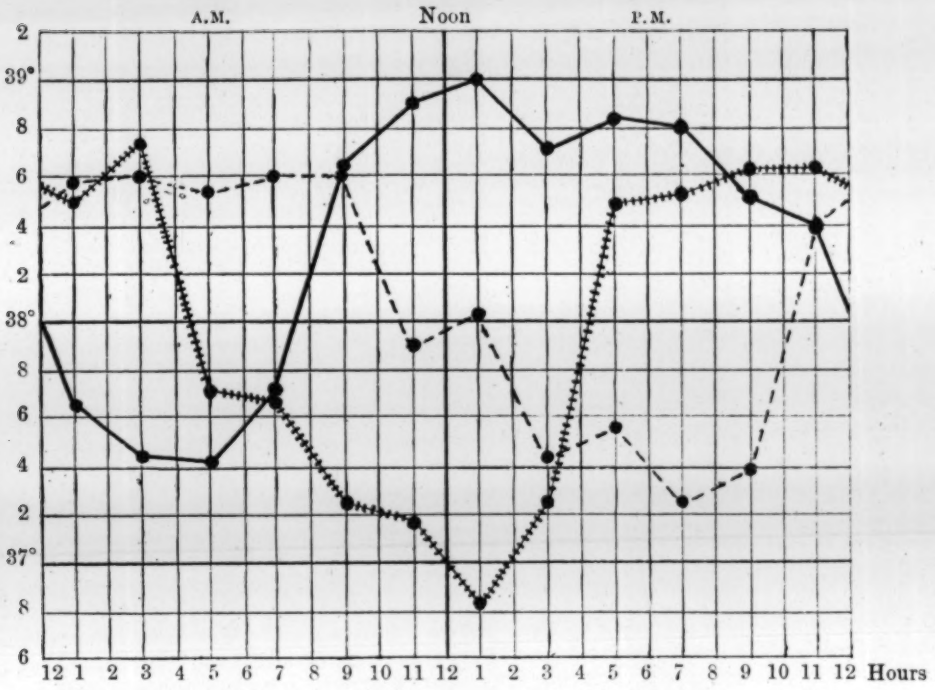

FIG. 1.—Mean diurnal temperature curve for Periods I., II., and III. in B (*Macacus rhæsus*), ♂ adult. The continuous line represents Period I., the interrupted line II., and the crossed line III.

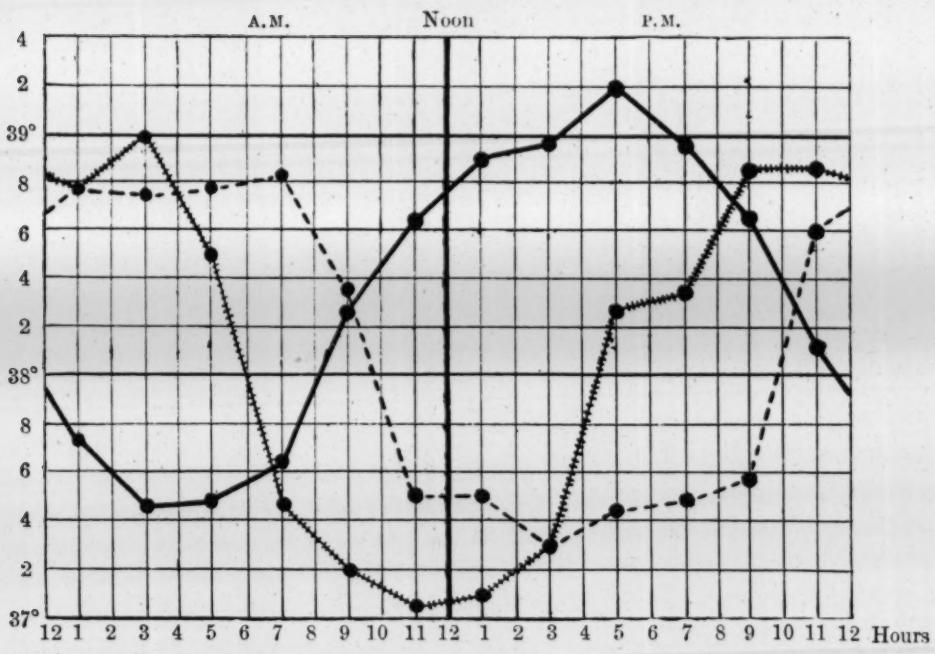

FIG. 2.—Mean diurnal temperature curve for Periods I., II., and III. in C (*Macacus rhæsus*), ♀ immature. The continuous line represents Period I., the interrupted line Period II., and the crossed line Period III.

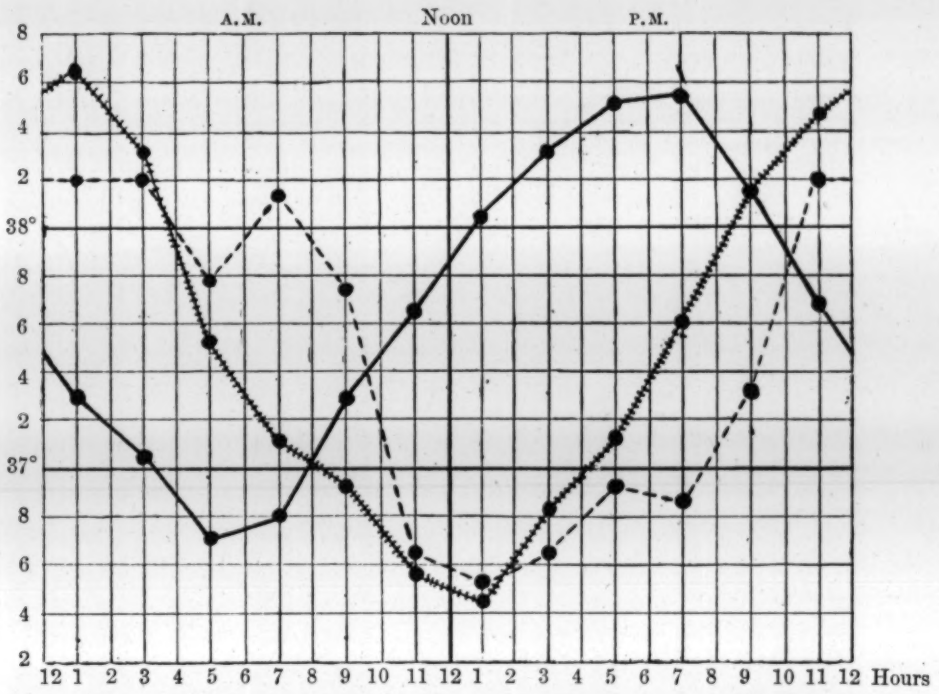

FIG. 3.—Mean diurnal temperature curve for Periods I., II., and III. in D (*Macacus cyanomolgus*), ♂ aged. The continuous line represents Period I., the interrupted line II., and the crossed line III.

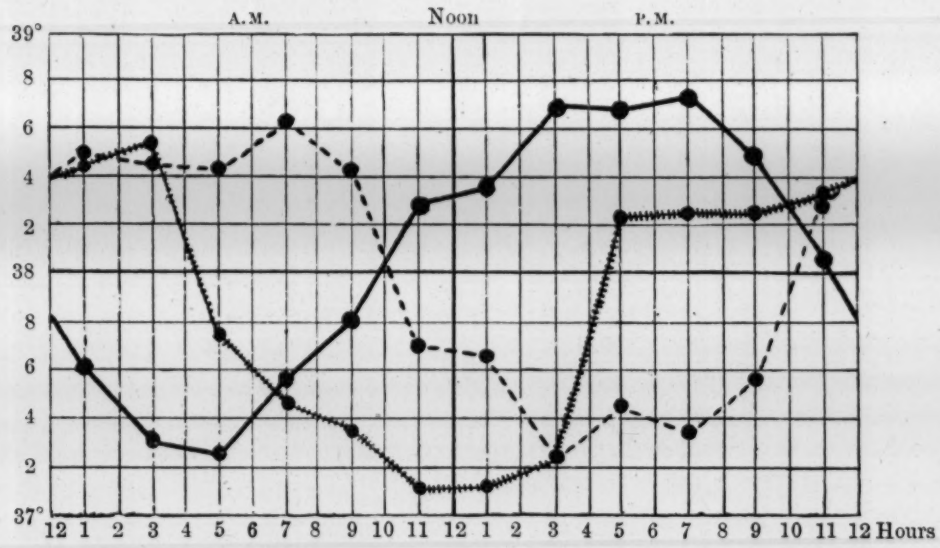

FIG. 4.—Mean diurnal temperature curve for Periods I., II., and III. in E (*Papio hamadryas*), ♀ adult. The continuous line represents Period I., the interrupted line II., and the crossed line III.

to 38·65), in E 1·44° (37·12 to 38·56), in F 0·89° (37·31 to 38·20), and in the compounded curve 1·63° (36·97 to 38·60). The range for the entire period was in B 2·5° (36·4 at noon on 21st to 38·9 at 5 p.m. on 20th and six subsequent occasions), in C 2·6° (36·7 at 1 p.m. on 23rd to 39·3 at 3 a.m. on 22nd and three other occasions), in D 3·4° (35·7 at 3 p.m. to 39·1 at 1 a.m. on 23rd), in E 2·1° (36·7 at 3 p.m. on 22nd, and 11 a.m. on 23rd, to 38·8 at 9 p.m. on 20th and three other occasions), in F 2·1° (36·6 at 3 p.m. on 22nd to 38·7 at 7 p.m. on 25th), and for the mean of all five 2·2° (36·6 at 3 p.m. on 23rd to 38·8 at 3 a.m. on 24th). The greatest range for any single day was in B 2·5° (36·4 at noon on 21st to 38·9 at 3 a.m. on 22nd), in C 2·6° (36·7 at 1 p.m. to

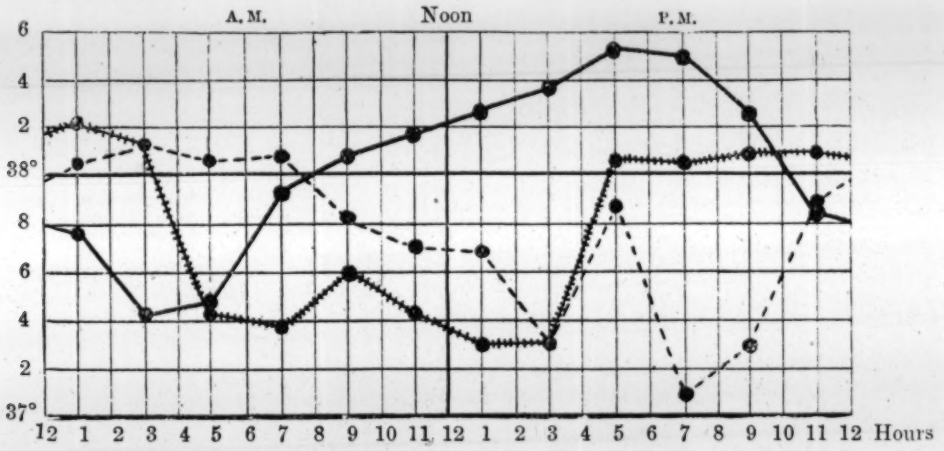

FIG. 5.—Mean diurnal temperature curves for Periods I., II., and III. in F (*Cercopithecus patas*), ♀ adult. The continuous line represents Period I., the interrupted line II., and the crossed line III.

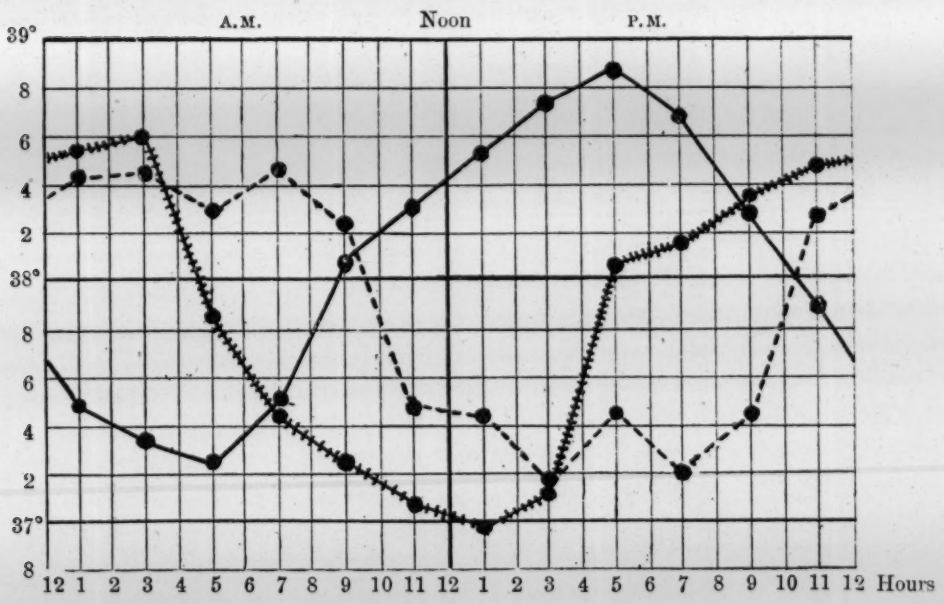

FIG. 6.—Mean diurnal temperature curves for Periods I., II., III. for all five monkeys, B, C, D, E, F. The continuous line represents Period I., the interrupted line II., and the crossed line III.

39·3 at 11 p.m. on 23rd), in D 3·4° (35·7 at 3 p.m. to 39·1 at 1 a.m. on 23rd), in E 2·1° (36·7 at 3 p.m. to 38·8 at 3 a.m. on 22nd), in F 1·7° (36·6 at 3 p.m. on 22nd to 38·3 at 11 a.m. on 21st), and for mean of all 2·2° (36·6 at 3 p.m. on 23rd to 38·8 at 3 a.m. on 24th).

The summary given in the following table shows how the mean temperature, range, and times of minima and maxima were affected by the conditions obtaining in Periods I., II., and III.

PERIOD I.—Normal. Resting from 9 p.m. to 9 a.m., Active from 9 a.m. to 9 p.m.

Monkey.	Mean Temperature.	Mean Range.	Minimum.	Maximum.
B . .	38·34	1·58	37·42 at 5 a.m.	39·0 at 1 p.m.
C . .	38·37	1·73	37·47 ,, 3 ,,	39·2 ,, 5 ,,
D . .	37·67	1·84	36·72 ,, 5 ,,	38·56 ,, 7 ,,
E . .	38·07	1·47	37·25 ,, 5 ,,	38·72 ,, 7 ,,
F . .	38·04	1·11	37·42 ,, 3 ,,	38·53 ,, 5 ,,
Average .	38·08	1·62	37·25 ,, 5 ,,	38·87 ,, 5 ,,

PERIOD II.—Inverted. Resting from 9 a.m. to 9 p.m., Active from 9 p.m. to 9 a.m.

B . .	38·08	1·35	37·25 at 7 p.m.	38·6 at 3 and 7 a.m.
C . .	38·08	1·51	37·30 ,, 3 ,,	38·81 ,, 7 a.m.
D . .	37·43	1·66	36·54 ,, 3 ,,	38·20 ,, 7 ,,
E . .	37·97	1·37	37·24 ,, 1 ,,	38·61 ,, 1 and 3 a.m.
F . .	37·75	1·05	37·09 ,, 7 ,,	38·14 ,, 3 a.m.
Average .	37·84	1·27	37·19 ,, 3 ,,	38·46 ,, 7 ,,

PERIOD III.—Resting from 3 a.m. to 3 p.m., Active from 3 p.m. to 3 a.m.

B . .	38·12	1·93	36·83 at 1 p.m.	38·76 at 3 a.m.
C . .	38·02	1·95	37·05 ,, 11 a.m.	39·00 ,, 3 ,,
D . .	37·48	2·18	36·47 ,, 1 p.m.	38·65 ,, 1 ,,
E . .	37·85	1·44	37·12 ,, 11 a.m.	38·56 ,, 3 ,,
F . .	37·75	0·89	37·31 at 1 and 3 p.m.	38·20 ,, 1 ,,
Average .	37·82	1·63	36·97 ,, 1 p.m.	38·60 ,, 3 ,,

The mean temperature is highest during the normal period and lowest during the third period; the diurnal variation is greatest during Period III. and least during Period II. Several days elapsed before the swing was well established; this will be evident from an examination of chart I., and when the mean temperatures of the first and last days of the reversed routine (Periods II. and III.) are contrasted (see fig. 7).

Effect of Darkness and Light.

To determine what part was played in the production of the diurnal wave by the alternation of light and darkness, two further experiments were undertaken. During the first of these—Period IV.—which extended from 3 a.m. on April 26th till 9 a.m. on May 2nd, the monkeys were kept continuously in the dark, except for the few

minutes every two hours occupied in taking the temperatures, when a single small electric lamp was used. They were fed at 9 a.m. and 6 p.m., but were otherwise left absolutely free, with no guide as to what routine they should adopt.

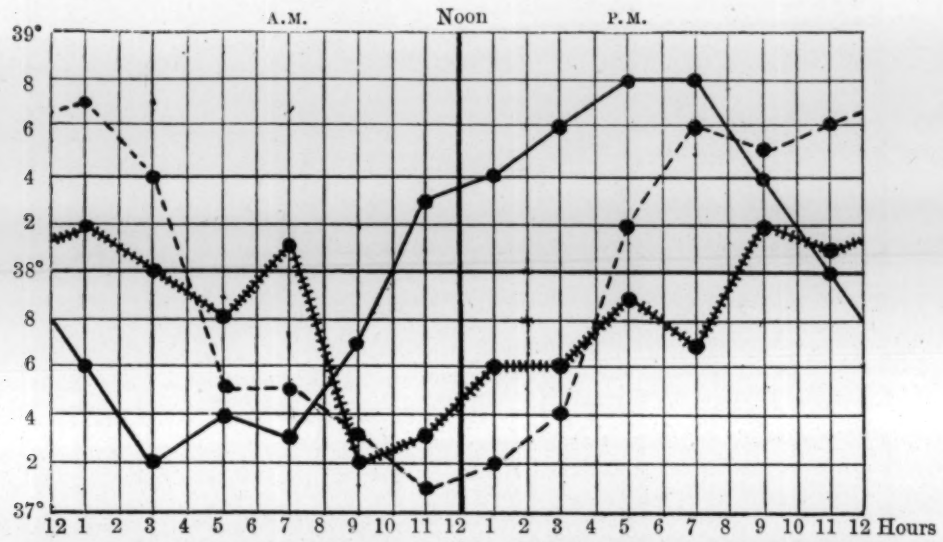

FIG. 7.—Compounded curves from all five monkeys for last day of normal period (continuous line), first day of Period II. (crossed line), and last day of Period III. (interrupted line).

The swing was carried forward from Period III., and is evident for the first few days in the plotted curves in chart I., but towards the end of this period it became very irregular, no two monkeys apparently observing the same routine of rest and activity. The most notable points are given in the following table:—

PERIOD IV.—CONTINUOUS DARKNESS FOR SEVEN DAYS.

	Mean Temperature.	Mean Range.	Minimum.	Maximum.
B . .	38·25	1 13	37·52 at 5 a.m.	38·65 at 9 p.m.
C . .	37·97	0·99	37·43 ,, 5 ,,	38·4 ,, 1 ,,
D . .	37·40	0·66	36·97 ,, 9 p.m.	37·63 ,, 5 and 9 a.m.
E . .	38·04	1·13	37·47 ,, 5 a.m.	38·60 ,, 9 a.m.
F .	37·88	0·94	37·48 ,, 5 ,,	38·42 ,, 11 ,,
Average .	37·91	0·73	37·47 ,, 5 ,,	38·20 ,, 11 ,,

On comparing this table with that of the normal Period I., it will be found that the mean temperature is in every case diminished, that the range is much diminished, and that with one exception (D) it has returned to the type characteristic of the normal Period I.—lowest in the morning and early forenoon, highest in the afternoon [see figs. 8 to 13, in which the mean curves of Periods IV. (interrupted line) and V. (crossed line) are contrasted with those of Period I. (continuous line)].

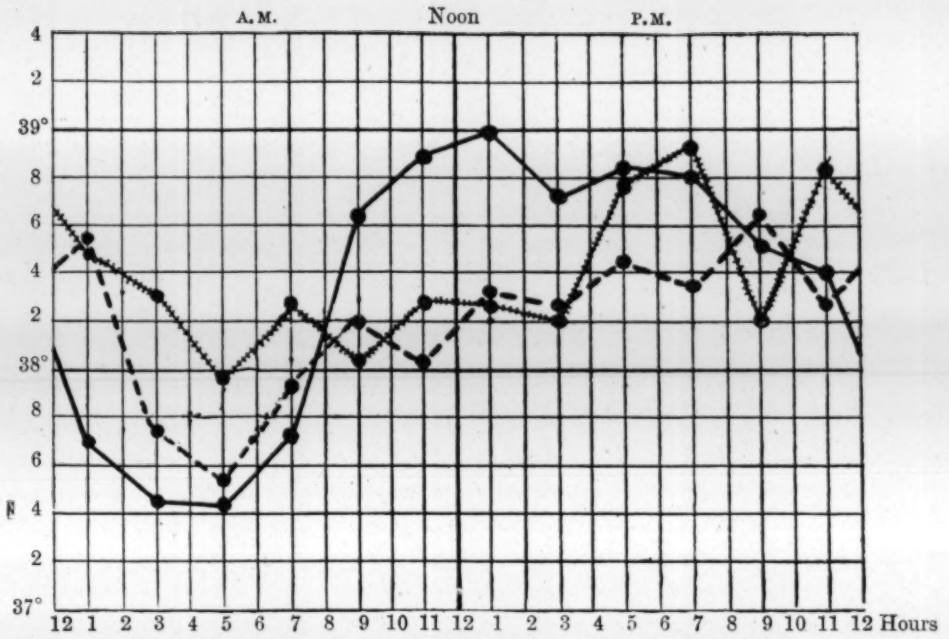

FIG. 8.—Mean diurnal curve of monkey B for Periods I. (continuous line), IV. (interrupted line), and V. (crossed line).

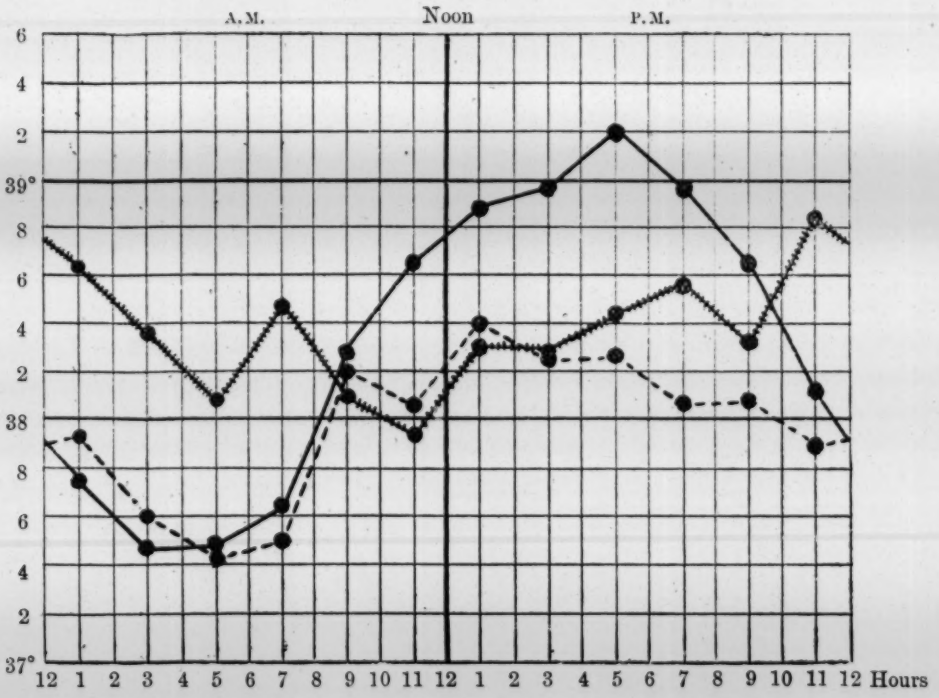

FIG. 9.—Mean diurnal curve of monkey C for Period I. (continuous line), IV. (interrupted line), and III. (crossed line).

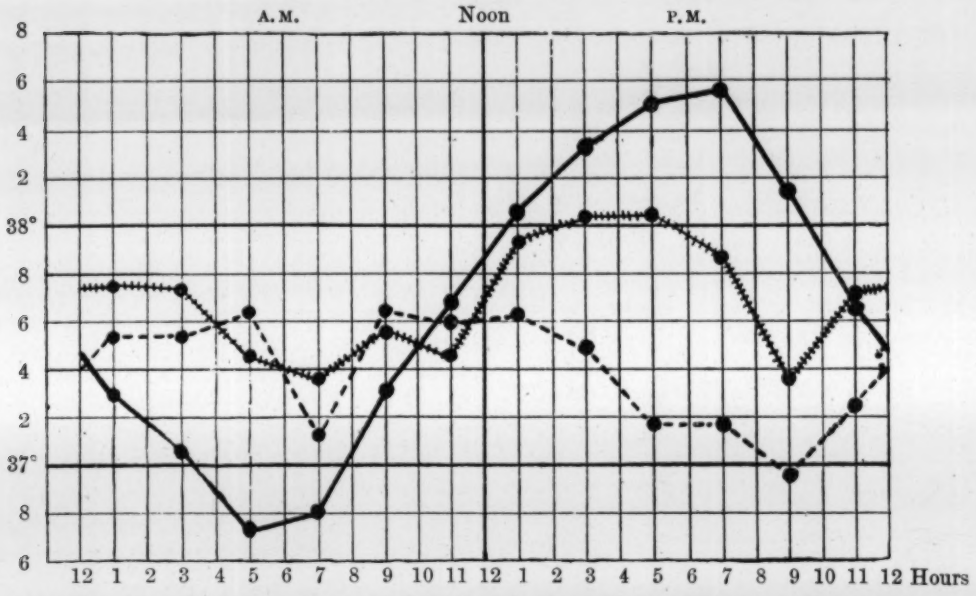

FIG. 10.—Mean diurnal curve of D for Periods I. (continuous line), IV. (interrupted line), and V. (crossed line).

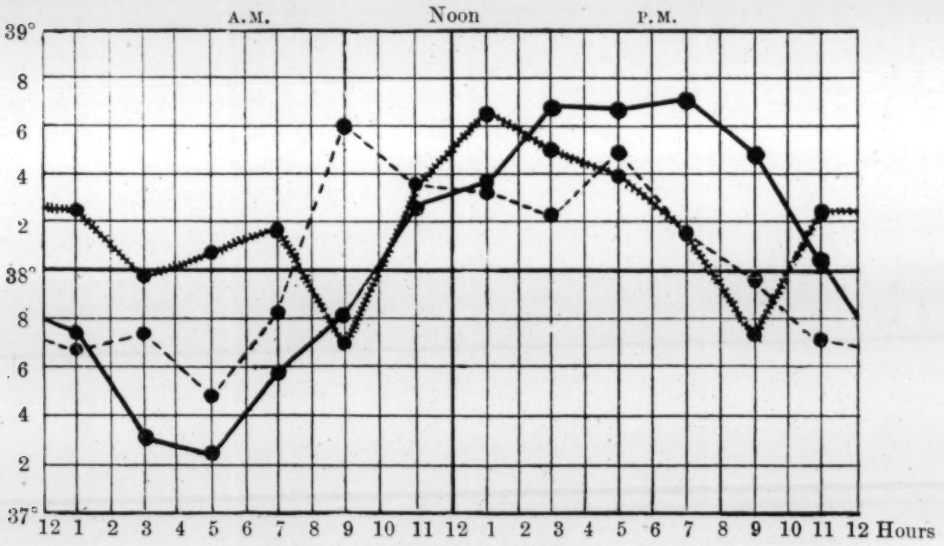

FIG. 11.—Mean diurnal curve of E for Periods I. (continuous line), IV. (interrupted line), and V. (crossed line).

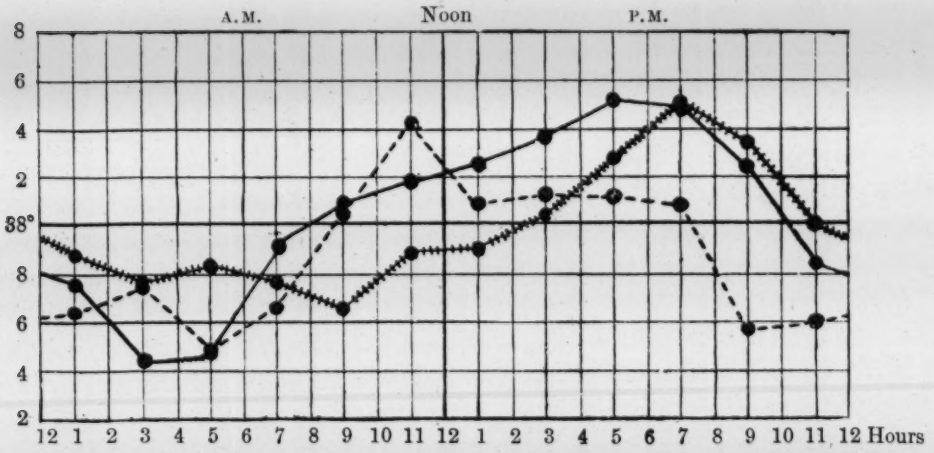

FIG. 12.—Mean diurnal curve of F for Periods I. (continuous line), IV. (interrupted line), and V. (crossed line).

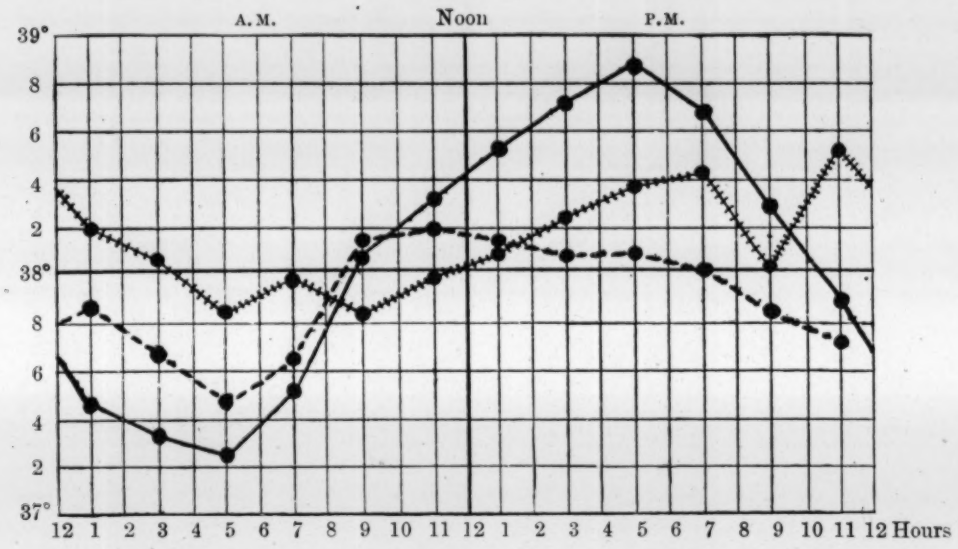

FIG. 13.—Mean diurnal curve compounded from all the monkeys for Periods I. (continuous line), IV. (interrupted line), and V. (crossed line).

The total range for the whole period is not much affected, but the times at which the daily minima and maxima are reached are very variable. The total range for B is 2·8° (36·6 at 5 a.m. on April 28th to 39·4 at 9 p.m. on May 1st), for C 2·2° (36·7 at 7 a.m. on 28th to 38·9 at 1 p.m. on 29th), for D 3·2° (36·1 at 7 a.m. on 29th to 39·3 at 1 a.m. on May 2nd), for E 2·0° (36·8 at 5 a.m. on 28th, and 1 a.m. on 29th, to 38·8 at 11 a.m. on 27th, and 11 a.m. on May 1st), in F 2·6° (36·3 at 5 a.m. on 28th to 38·9 at 7 a.m. on May 2nd), and for the mean of all 1·8° (36·9 at 5 a.m. to 38·7 at 11 a.m. on 28th).

PERIOD V.—CONTINUOUS LIGHT.

This extended from 9 a.m. on May 2nd till 9 p.m. on May 8th. The room was illuminated by daylight during the day, and by a powerful electric light during the night, but otherwise the conditions were similar to those obtaining throughout the preceding period, and the general effect on the temperature curves was similar. From an examination of chart I. it might appear that all rhythm had been abolished (the gap is due to the fact that one of the observers was unable to take his place on May 3rd), but when the twenty-fourly means for the whole period are scrutinised it will be found that this is not the case (see figs. 8 to 13—crossed line—pp. 91–93). In fig. 13 the type of curve of this period conforms as nearly to that of the normal (continuous line) as does that of Period IV. (interrupted line).

PERIOD V.—CONTINUOUS LIGHT FOR 6 DAYS.

	Mean Temperature.	Mean Range.	Minimum.	Maximum.
B . .	38·39	0·96°	37·97 at 5 a.m.	38·93 at 7 p.m.
C . .	38·35	0·87	37·95 ,, 11 ,,	38·82 ,, 11 ,,
D . .	37·69	0·65	37·37 ,, 9 p.m.	38·02 ,, 3 and 5 p.m.
E . .	38·18	0·85	37·67 ,, 9 a.m.	38·52 ,, 3 p.m.
F . .	37·89	0·87	37·65 ,, 9 ,,	38·52 ,, 7 ,,
Average .	38·12	0·70	37·82 ,, 9 ,,	38·52 ,, 11 ,,

The mean temperature in every case is higher than in Period IV., but the mean range is less. The maximum is always reached in the afternoon and the minimum, with one exception (D), in the forenoon ; this shows that both during Periods IV. and V. there was a tendency for the monkeys to fall back into the normal (Period I.) routine, although the incidence of light and darkness did not act as a signal for activity and rest. In fig. 14, the crossed line represents the mean compounded curve for all the monkeys on the last day of Period IV., the interrupted line the same on the last day of Period V., and the continuous line that on the last day of the normal Period I. It is evident here that the curve obtained at the end of Period V. corresponds much more closely to the normal curve than does that taken at the beginning of Period IV. This would appear to point to the fact that when left to themselves without any guidance from the outside the monkeys tend to adopt the normal rhythm. The curve at the end of Period V. differs from the normal in its diminished amplitude (excluding the last figure 38·9) and in its regularity.

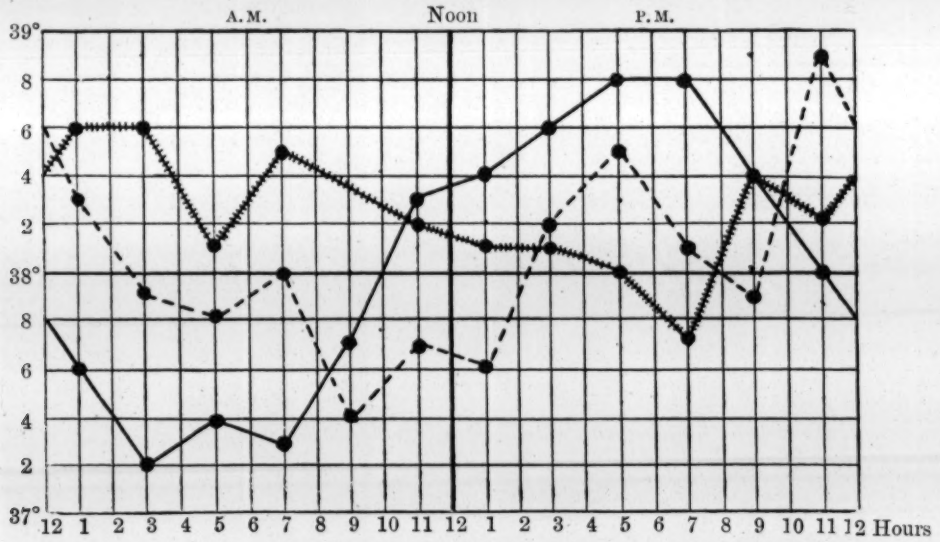

FIG. 14.—Compounded curves from all the monkeys for last day of normal period (I.) (continuous line), last day of Period IV. (crossed line), and last day of Period V. (interrupted line).

The range for the whole period was for B 2·5° (36·9 at 3 p.m. on 7th to 39·4 at 7 p.m. on 6th), for C 2·5° (36·8 at 1 p.m. on 8th to 39·3 at 5 p.m. on 6th), for D 2.5° (36·3 at 9 p.m. on 8th to 38·8 at 3 p.m. on 6th), for E 2·2° (36·7 at 9 p.m. on 1st to 38·9 at 3 p.m. on 4th), for F 2·5° (36·8 at 3 p.m. on 7th to 39·3 at 7 p.m. on 4th), and for the mean of all the monkeys 1·5° (37·4 at 9 a.m. on 8th to 38·9 at 11 p.m. on 7th). Towards the end of this period the monkeys became very irritable and ill-tempered.

EFFECT OF INANITION.—PERIOD VI.

After an interval of about three weeks, in which the monkeys were permitted to resume their normal routine—rest during the night and activity during the day—we began another experiment,* with a view to determine the effect of the ingestion of food on the mean temperature and its diurnal variation. Period VI. extended from 6 p.m. on May 29th till 6 p.m. on June 1st, and during this time (72 hours) the monkeys were supplied with water, but were deprived of all other food. Throughout the fore-period—from 1 p.m. May 26th till 6 p.m. May 29th—and the after-period—from 6 p.m. June 1st till 5 p.m. June 4th—two-hourly records were made in the ordinary way under conditions as in Period I. (normal) with regard to feeding, rest, exercise, etc., for comparison with the readings taken while the animals were deprived of food. The results are presented briefly in tabular form below.

The mean temperature for the starvation period was in every case lower than for the fore-period, which may be taken as the normal. The fall was greatest during the second day, with one exception (D), taking the mean of the fore-period as the normal. In the subjoined table the sign + indicates a rise, and the sign − a fall. In two cases, D and E, there is a slight rise during the last day, and in B and C

	B.	C.	D.	E.	F.	Average.
1st day .	+ ·17	+ ·29	− ·34	− ·02	− ·08	+ ·02
2nd ,, .	− ·74	− ·88	− ·05	− ·69	− ·20	− ·56
3rd ,, .	− ·59	− ·21	+ ·16	+ ·38	− ·14	− ·05

during the first day. Taking all the monkeys together (average column), it may be stated generally that there was a very slight rise the first day, a marked fall the second day, and a slight fall the third day. The rise during the first day is difficult to explain, unless it be due to the fact that the animals were searching about for food and were more active than usual.

The mean temperature of the after-period was in two cases (B and C) lower than that of the starvation period, and in the remaining three cases (D, E, F) higher, and in two cases (D and F), it was higher than that of the fore-period. During the after-period, the greatest rise takes place also during the second day. The only

	B.	C.	D.	E.	F.	Average.
1st day .	+ ·13	− ·09	+ ·74	− ·09	+ ·06	+ ·01
2nd ,, .	+ ·27	+ ·37	− ·21	+ ·21	+ ·43	+ ·32
3rd ,, .	+ ·32	− ·22	− ·85	+ ·02	+ ·27	+ 09

marked exception to this is D, in which there is a distinct rise in the first day and then a fall on each succeeding day, but this is probably due to the fact that

* This was carried out by one of us alone (S. S.).

PERIOD VI.

	Mean Temperature.			Temperature Range, Minima and Maxima.									Times of Occurrence of Minima and Maxima.					
				Fore-Period.			Starvation Period.			After-Period.			Fore-Period.		Starvation Period.		After-Period.	
	Fore-Period.	Starvation Period.	After-Period.	Range.	Min.	Max.	Range.	Min.	Max.	Range.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
B.	38·61	38·13	38·01	1·62	37·63	39·25	1·21	37·66	38·87	2·2	37·0	39·2	3 a.m.	7 p.m.	1 a.m.	3 p.m.	1 a.m.	5 p.m.
	1st day	38·88	37·68	.	.	.	1·7	37·7	39·4	3·0	36·4	39·4	.	.	1 ,,	9 a.m.	1 ,,	5 ,,
	2nd ,,	38·14	37·95	.	.	.	1·4	37·2	38·6	2·2	37·2	39·4	.	.	7 p.m.	1 & 3 p.m.	7 & 9 a.m. & 11 p.m.	5 ,,
	3rd ,,	37·55	38·27	.	.	.	1·8	36·9	38·7	2·1	37·2	39·3	.	.	3 a.m.	3 ,,	3 a.m.	3 ,,
C.	38·43	38·02	37·75	1·33	37·77	39·10	1·24	37·63	38·87	1·55	37·10	38·65	5 ,,	7 ,,	11 p.m.	3 ,,	1 ,,	3 ,,
	1st day	38·72	37·54	.	.	.	1·6	38·0	39·6	1·5	36·7	38·2	.	.	11 ,,	3 ,,	1 ,,	5 & 7 ,,
	2nd ,,	37·84	37·91	.	.	.	1·9	36·8	38·7	2·1	36·9	39·0	.	.	9 a.m.	5 ,,	9 p.m.	3 ,,
	3rd ,,	37·63	37·69	.	.	.	1·5	36·9	38·4	2·0	36·9	38·9	.	.	5 ,,	3 & 5 ,,	1 & 3 a.m. & 1 p.m.	5 ,,
D.	37·47	37·15	37·57	1·65	36·57	38·22	1·90	36·27	38·17	2·2	36·43	38·63	5 ,,	5 & 7 ,,	5 ,,	11 a.m.	9 a.m.	5 ,,
	1st day	37·13	37·98	.	.	.	2·0	36·0	38·0	2·6	37·1	39·7	.	.	3 & 5 ,,	5 & 9 p.m.	11 p.m.	1 ,,
	2nd ,,	37·08	37·77	.	.	.	3·1	35·7	38·8	2·3	36·3	38·6	.	.	1 ,,	3 a.m.	9 a.m.	3 & 5 ,,
	3rd ,,	37·24	36·92	.	.	.	2·7	36·0	38·7	2·8	35·6	38·4	.	.	3 & 7 ,,	11 a.m. & 5 p.m.	5 & 9 ,,	7 ,,
E.	38·33	37·98	38·08	1·37	37·73	39·10	0·80	37·60	38·40	1·18	37·47	38·65	3 ,,	9 ,,	9 p.m.	1 a.m.	9 ,,	3 ,,
	1st day	38·31	37·91	.	.	.	0·70	38·0	38·7	1·2	37·2	38·4	.	.	5 & 9 a.m.	11 p.m.	9 ,,	7 ,,
	2nd ,,	37·62	38·12	.	.	.	1·2	37·0	38·2	1·8	37·4	39·2	.	.	11 ,,	7 ,,	9 ,,	1 ,,
	3rd ,,	38·00	38·14	.	.	.	1·4	37·2	38·6	1·8	37·1	38·9	.	.	1 ,,	1 ,,	5 ,,	7 ,,
F.	37·78	37·61	38·10	0·92	37·30	38·22	0·6	37·33	37·93	1·20	37·37	38·57	5 ,,	3 & 7 ,,	1 ,,	3 ,,	9 ,,	5 ,,
	1st day	37·70	37·70	.	.	.	1·5	36·8	38·3	1·90	36·7	38·6	.	.	5 ,,	1 ,,	9 ,,	7 ,,
	2nd ,,	37·50	38·13	.	.	.	1·2	37·0	38·2	1·7	37·3	39·0	.	.	7 ,,	7 ,,	1 ,,	11 a.m.
	3rd ,,	37·64	38·40	.	.	.	1·1	36·9	38·0	1·2	37·6	38·8	.	.	11 p.m.	3 & 7 a.m.	7 ,,	5, 7 & 11 p.m.
Average.	38·12	37·73	37·87	1·25	37·47	38·72	0·9	37·4	38·3	1·36	37·30	38·66	3 ,,	7 ,,	3 a.m.	3 p.m.	3 & 5 ,,	5 p.m.
	1st day	38·14	37·76	.	.	.	1·0	37·6	38·6	1·5	37·2	38·7	.	.	3 & 5 ,,	3 ,,	1 & 5 ,,	5 ,,
	2nd ,,	37·58	37·95	.	.	.	0·9	37·1	38·0	1·6	37·2	38·8	.	.	9 p.m.	1, 3 & 5 p.m.	9 ,,	1 ,,
	3rd ,,	37·63	37·86	.	.	.	1·2	37·1	38·3	1·8	37·0	38·8	.	.	1 a.m. & 11 p.m.	11 a.m. & 3 p.m.	3 ,,	7 ,,

he was suffering from symptoms of gastro-intestinal irritation (vomiting and diarrhœa) produced by over-eating. In these circumstances he could not be considered normal, and so is excluded from the average column in this period. From that column it may be stated that in the after-period there is a slight rise the first day, a distinct rise the second, and a slight rise the third, and that after three days of full feeding the mean temperature has not returned to the normal. The mean temperature of B, C, E, and F, for the fore-period is 38·29, and for the last day of the after-period 38·12, *i.e.* ·17 below the normal.

The mean diurnal range was less in the starvation period than in either the fore- or after-periods, with D again as an exception, and it was greatest in the after-period.

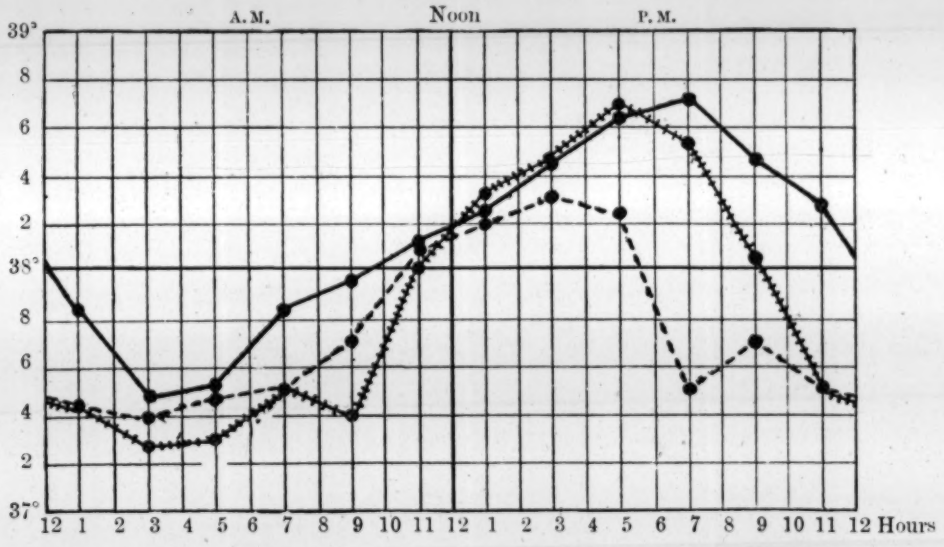

FIG. 15.—Compounded curves from all the monkeys for fore-period (continuous line), starvation period (interrupted line), and after-period (crossed line).

This is seen in fig. 15, in which the mean curves for all the monkeys are represented for the three periods.

Fig. 16 shows curves compounded from the records of all the monkeys for the first day of the fore-period (continuous line), the first day of the starvation period (interrupted line), and the last day of the starvation period (crossed line). In its general characters the curve for the first day of the starvation period agrees with the normal curve, but the type of curve for the last day of that period is different; it falls distinctly below the level of the others, and the maxima elevations are reached earlier in the day.

CONCLUSIONS.

Mean temperature.—On account of the fact that there is in the monkey a very distinct diurnal variation, the temperature will vary considerably according to the period of the day at which the observations are made, and it has probably been stated too high by most observers, since no one, so far as we know, has taken the temperature in the

early hours of the morning, when it is lowest. HALE WHITE and WASHBOURN (8) give the mean rectal temperature as 38·4° C. This average figure was obtained from two *rhæsus* monkeys, the observations, 22 in number, being made at different hours between 8.30 a.m. and 11.45 p.m. on seven consecutive days; none were made between midnight and 8.30 a.m. ARUCH (9) from 17 observations found it to be 38·3, COUTY (10) (5 observations) 38·1, RICHET (11) (2 observations) 38·35, and LEFEVRE (12) 38·5. These were all taken during the day.

In thirty-one monkeys (macacus) we have made 393 observations on the temperature of the axilla, and 331 on that of the rectum, mostly between 5 and 6 p.m., a few between 2 and 3 p.m. and between 9 and 10 a.m., and the mean for the axilla is 38·6, for the rectum 38·5. In one monkey (XXX.) on which observations were made continuously for a week, the forenoon mean (between midnight and noon) was, for the axilla 37·1, for the rectum 36·9, and the afternoon mean (noon to midnight), for the axilla 38·3, for the rectum 38·2; while for the whole period it was, axilla 37·8, and rectum 37·6.

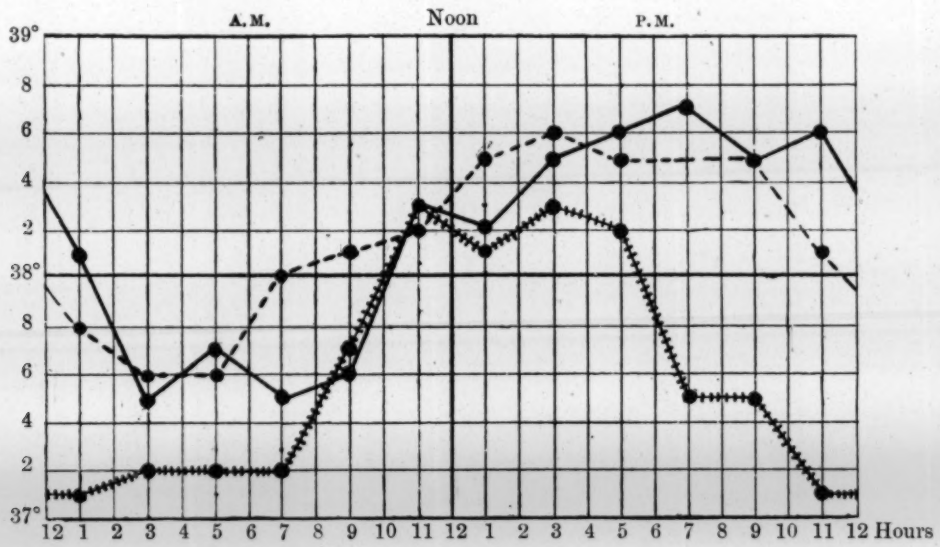

FIG. 16.—Compounded curves from all the monkeys for first day of fore-period (continuous line), first day (interrupted line), and last day (crossed line) of starvation period.

In another monkey (XXXI.) under the same conditions it was, for the forenoon, axilla 37·9, rectum 37·6, for the afternoon, axilla 38·7, rectum 38·4, and for the whole period, axilla 38·2, rectum 38·0. In five monkeys in which two-hourly observations were made continuously for fifteen days (Period I. and first part of Period VI.) on the axilla only, the forenoon mean was 37·7, the afternoon mean 38·5, while for the whole time it was 38·1 (786 observations).

The normal temperature of the monkey may be stated then to be about one degree centigrade higher than that of man. RICHET says that the rectal temperature of man in health varies between 36·4 and 37·6; the mean may be taken as 37·2; it is about 2° C. below the temperature of most mammals and 5° C. below that of birds. Thus

with regard to its mean temperature the monkey may be placed intermediate between man and most of the higher mammals.

Diurnal variation.—This is considerably greater than in man and many of the lower animals. According to JÜRGENSEN and LIEBERMEISTER (13), and many other observers (14), the range in man is about 1° C., the maximum being reached between 5 and 8 p.m. and the minimum between 3 and 6 a.m. In the lower animals few exact observations have been made throughout the day and night. BIDDER and SCHMIDT (15) in a cat found a mean range for 11 days (24 hours) of 1·3—minimum 37·8 between 6 and 8 a.m., maximum 39·08 between 8 and 10 p.m. STRECKER (16), SIEDAMGROTZKY (17), HOBDAY (18), and LISKA (19) in horses, HUNTER (20) in the ass, ROBERTSON (21) in oxen, CARTER (22) in the rabbit, cat, and dog, REICHERT (23) in the dog, and CORIN and VAN BENEDIN (24) in pigeons, have all found evidence of a distinct and fairly constant diurnal variation, which may be generally stated to be from 1° to 2° C.

HALE WHITE and WASHBOURN (8) in two healthy *rhæsus* monkeys found the range to be about 3·5° C. From observations on five healthy monkeys extending over a period of 12 days (Period I.), we have found the mean diurnal variation to be 1·58, 1·73, 1·84, 1·47, and 1·11 respectively, giving an average figure for the whole five of 1·62. The minimum was reached between 3 and 5 a.m., and the maximum between 5 and 7 p.m. The greatest range in any single day of 24 hours for any individual monkey was 3·4° (35·8–39·2), and the least 2° (36·8-38·8). The range of the diurnal temperature variation is therefore two or three times as great as in man.

Effect on diurnal variation of changing the daily routine.—Several attempts have been made to investigate the influence of the inversion of the daily routine in the human subject. DEBCZYNSKI (25) found in healthy individuals that:—1. Muscular exercise raised the body temperature in direct proportion to its intensity and duration from 0·1° to 0·3° C. after ½ to 2 hours' work. 2. Muscular work carried on through the night inverted the daily temperature curve, and gave the highest temperature in the morning (37·8) and the lowest in the evening (35·3). 3. Night watching without muscular work produced a similar inversion only with a smaller swing—37·7 in the morning and 37·5 in the evening. The original article is not obtainable by us, and in the short abstract in the reference no details are given, and it is not stated how the temperature was taken. KRIEGER (26) has also shown that when an individual sleeps during the day and works during the night his temperature curve is inverted. BUCHSER (27), an engineer who was accustomed to sleep through the day and to work at night, found that his morning temperature oscillated between 37 and 37·5, while the evening record was between 36·6 and 37, averaging 36·8. JAEGER (28) made an extended series of observations on five young men (military bakers) whose daily routine was as follows:—They worked from 3 a.m. to 4 p.m. in a heated room; they rested from 4 to 7 p.m.; from 7 to 8 p.m. they had light work, and from 8 p.m. to 3 a.m. they slept. JAEGER concluded from these observations that night work and

day rest produced an inversion of the temperature curve. Thus, all these observers came to the same conclusion, viz.—that by inverting the daily routine the temperature curve may be inverted, but in many cases the details are wanting, and where they are given the conditions are often open to criticism.

In 1885 U. Mosso (7) made an experiment on himself. He first obtained his normal curve by taking the rectal temperature for several days consecutively under his usual daily routine. He slept from 11 p.m. till 6 a.m. Two meals were taken, one at 11 a.m., the other at 6 p.m. During the second period, which lasted four days, he worked during the night and rested during the day, sleeping from 11 a.m. till 6 p.m., and he now took his meals at 11 p.m. and 6 a.m. Throughout almost the whole experiment he remained in one room, the temperature of which only varied between 12° and 17° C., and the greater part of his working time was spent seated at a table either reading or writing; he did no active muscular work. Notwithstanding this inversion of the daily routine the morning rise still took place at about the same time, and the normal curve was considerably modified by the fact that sleep during the day produced a marked fall, but it was not inverted.

The most recent and by far the most accurate research on this subject is that of Benedict (6), carried out in America (1903). For the details the reader is referred to the original paper. Suffice it to say that he did not find the temperature curve to be inverted even in an individual who had been a night watchman for a period of eight years, during the whole of which time he had slept during the day and been active during the night. The curve was approximated more or less closely to a straight line, but it was not inverted. From these experiments of Mosso and Benedict, then, which were conducted far more systematically than those of the earlier observers, we may take it that in man inversion of the daily routine produces a modification of the temperature curve, but does not lead to its total inversion.

So far as we know, ours is the first attempt to study this subject in animals. We have already stated our reasons for selecting the monkey, viz.—the susceptibility of its temperature to the outside influences which are supposed to be the cause of the diurnal variation. Unlike Mosso and Benedict in the human subject, we have succeeded in inverting the temperature curve in the monkey. The range, it is true, is somewhat more variable than under normal conditions, but the inversion is nevertheless complete. Still there is a certain amount of fixity in the normal variation curve, although this is not nearly so pronounced as it is in man. This is evident from the fact that when the monkeys were left to themselves during Periods IV. and V. (continuous darkness and continuous light), without any signal from without as to what routine they should adopt, the curve returned to the normal type (figs. 8–13, pp. 91–93). Temperature control is therefore much more complete in man than in the monkey, as is shown by the greater range in the latter and the readiness with which its normal wave may be disturbed. The two chief factors which govern the diurnal variation are probably muscular exercise and sleep, *i.e.* the condition of the great heat-producing

system, and of the temperature-controlling system. The effect of muscular exercise on the body temperature is well known. JÜRGENSEN (29) found that sawing wood for six hours raised the rectal temperature of a healthy man 1·2° C. In one of ourselves a sharp walk of an hour and a quarter on a cold frosty night caused an elevation of the temperature of the rectum of 1·1° C. OBERNIER (30), OGLE (31), CROMBIE (32), and many others have found the same. Quite recently BLAKE and LARRABEE (33) have studied the effect of severe muscular exercise on forty-five long-distance runners ; the course was twenty-four miles. The temperature was taken by the mouth at the start, and by the mouth and rectum at the finish. Very often the mouth temperature was lower at the finish than at the start, but the rectal temperature was invariably higher, except in three cases, where the runners had taken considerable quantities of alcohol during the race. The highest rectal temperature reached was 40·2° C., and this by three separate individuals. Unfortunately the rectal temperature was not taken immediately before the start, but supposing it to be normal—37·2—the elevation would be 3° C. One of the important facts demonstrated by these observations is that the mouth temperature is not a reliable factor, especially after active exercise. By relying on the mouth temperature, MARCET (34) and LORTET (35) were led into the error of supposing that mountain climbing lowers the temperature. BENEDICT (6) found that the body temperature was sensitive to even the minor muscular movements implied in changing the position of the body.

In animals the same effect has been observed. RICHET (36) tied up a dog and placed a very delicate thermometer in its rectum, graduated in 50ths of a degree. As a rule, if the dog remained immobile the temperature did not vary and might remain for some hours almost fixed ; but if the dog struggled or was excited for even $\frac{1}{4}$ minute, the temperature rose, 2, 3, or it might be 5, 50ths of a degree, and after the temperature had risen 5/50° C. it took about ten minutes to return to what it was before the movement was made. Also by causing pigeons to fly with a weight attached to them, he found that the temperature was raised from 1° to 2° C. in a few minutes. MOTT (37) has noticed a rise of 1° to 2° C. in the temperature of monkeys after a short chase, and we have observed a similar rise under the same conditions.

With regard to the effect of sleep there is not the same unanimity of opinion. According to BÄRENSPRUNG (38) and WUNDERLICH (39), sleep has no effect on the temperature, but on the other hand CROMBIE (40), HUNTER (41), LIEBERMEISTER (42), and many others have found that during sleep the temperature always falls. In the experiments of MOSSO (7) and of BENEDICT (6), sleep during the day caused a very distinct fall, and seemed to be the most important factor in modifying the curve.

Muscular exercise appears therefore to be the chief cause of an elevation of the body temperature, and this becomes most effective in those animals in which the temperature regulating mechanism is least highly developed ; in monkeys it is more effective than in man. Sleep, on the other hand, or a depressed condition of the heat-regulating centres (the central nervous system), is probably the chief cause of a fall in the

temperature, and when these two conditions are reversed with regard to the incidence of night and day, the diurnal variation curve is inverted.

The effect of the ingestion of food.—This, RICHET (43) thinks, is probably only feeble. A heavy dinner at 7 p.m. does not appreciably prevent the temperature from falling, and the want of a mid-day meal does not prevent it rising. There is always an increase in heat production after food, but CARTER (5) has proved that body temperature and heat production do not run parallel. In the case of individuals who have abstained from food for even a very long time, the mean temperature is little affected. TANNER (44) showed no fall in temperature after a 30 days' fast. LUCIANI (45) found the same in the fasting man Succi, and MERLATTI (46) had a temperature only very slightly below the normal—36·8—after 43 days' abstinence. This is assuming that these fasts were genuine.

The lower animals seem to differ somewhat from man in this respect. In two geese deprived of food, BARDIER (47) found the rectal temperature to be 40° and 39·5° respectively on the twelfth day, and on the seventeenth day, when they had lost 37 per cent. of their body weight, it was 39·1° and 39·2°. He does not state the temperature before the experiment was begun. In animals and birds the effect on the temperature appears to be most evident on the first or second day of the fast. MARTIUS (48) found the average temperature of four well-nourished ducks to be 42·2°; they were then deprived of food, and after 24 hours' fasting it was 41·84°; after 48 hours, 41·8°; after 72 hours, 41·91°; after 90 hours, 41·94°; and at the end of 120 hours it was 41·62°. The fall was thus greatest during the first day. CHOSSAT (40) has shown that the same obtains in pigeons. In a fasting cat, BIDDER and SCHMIDT (50) found that in 355 hours the rectal temperature had fallen from 39·08° to 38·4°; in 369 hours, to 38·1°; in 393 hours, to 35·5°; and in 426 hours, to 32·4°, when the animal died. These experiments on the lower animals and birds in the fasting state appear to point to the fact that the temperature falls somewhat rapidly the first and second day, then very slowly, if at all, till towards the end, when there is a sudden and rapid fall immediately preceding death.

In our observations on monkeys which fasted 72 hours, we have found that the fall of temperature was greatest during the second day, in three cases amounting to nearly 1° C. (For details see pp. 95–96.) In some cases the mean for the first day showed a slight rise, in other cases a slight fall, and similarly for the third day, but in every case the second day showed a fall. The average mean temperature of the five monkeys showed a slight rise the first day—0·02°; a marked fall the second day—0·56°, and a slight fall the third day—0·05°, when the experiment was stopped. Similarly, during the after-period, when feeding was resumed, the change was most marked on the second day. The average mean for this period showed a slight rise for the first day—0·01°, a distinct rise for the second—0·32°, and a slight rise for the third day—0·09°, but it was still at the end of the third day 0·17° below the normal. The mean diurnal range* was less in the starvation period than in either the fore- or after-periods, with one

* The range for the last day of the starvation period was not diminished.

exception (see fig. 15, p. 97). This does not agree with what CHOSSAT found in pigeons. In his experiment during the period of inanition the daily variation became much exaggerated.

From our experiments, then, we may conclude that the temperature of the monkey is much more influenced by the withholding of food for abnormally long periods than is that of man, and in this respect, as in others, *e.g.* muscular exercise, it is more sensitive to those external conditions which are held to modify the body temperature.

SUMMARY.

1. The mean rectal temperature of the monkey may be stated to be 38° C.—about 1° C. higher than that of man.

2. The range of the diurnal temperature variation is from 2° to 3° C.—twice or thrice as great as in man.

3. In the monkey the temperature of the axilla is as a rule from 0·1 ° to 0·2° C. higher than that of the rectum.

4. The temperature is more susceptible to outside influences than in man, *e.g.* muscular exercise, and inversion of the daily routine leads to an inversion of the diurnal temperature curve. The experiments of Mosso and of BENEDICT show that this is not the case in man.

5. Nevertheless, when monkeys are left to themselves in continuous darkness or continuous light, the temperature curve tends to assume the normal type.

6. Total darkness for a week was found to lower the mean temperature 0·4° C. below the normal, but continuous exposure to the light (natural and artificial) for the same time did not raise it above the normal.

7. Total abstinence from solid food for three days produced a distinct fall in the temperature, which was most marked during the second day, and at the end of three days after feeding was resumed it had not returned to the normal.

8. Temperature control in man is much more complete than in the monkey or any of the lower animals.

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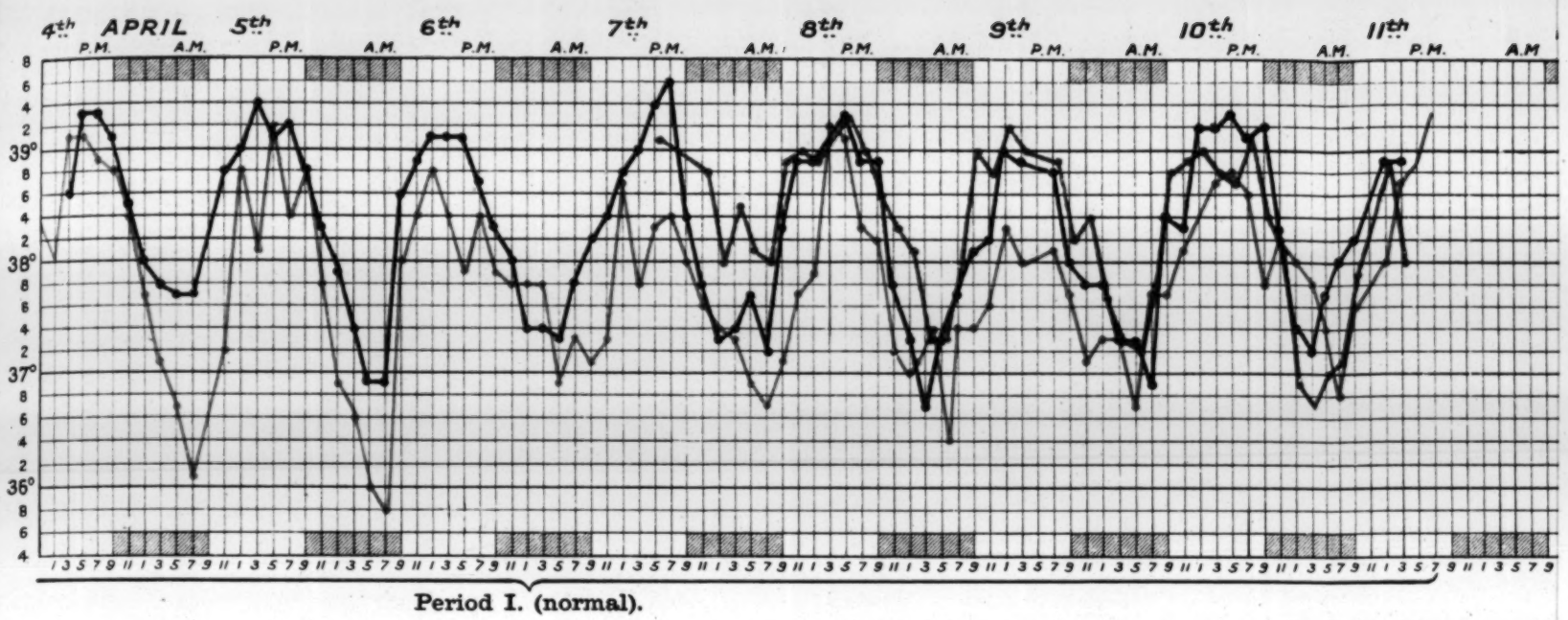
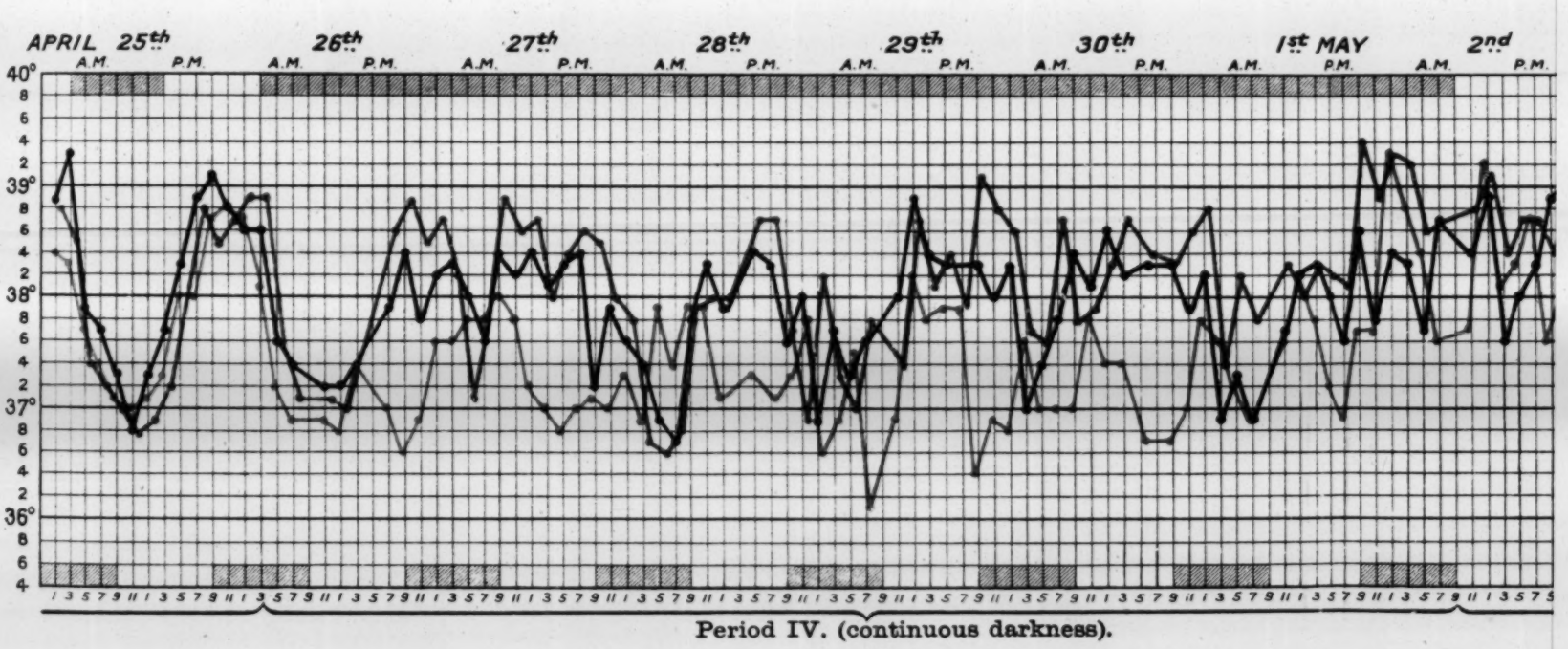
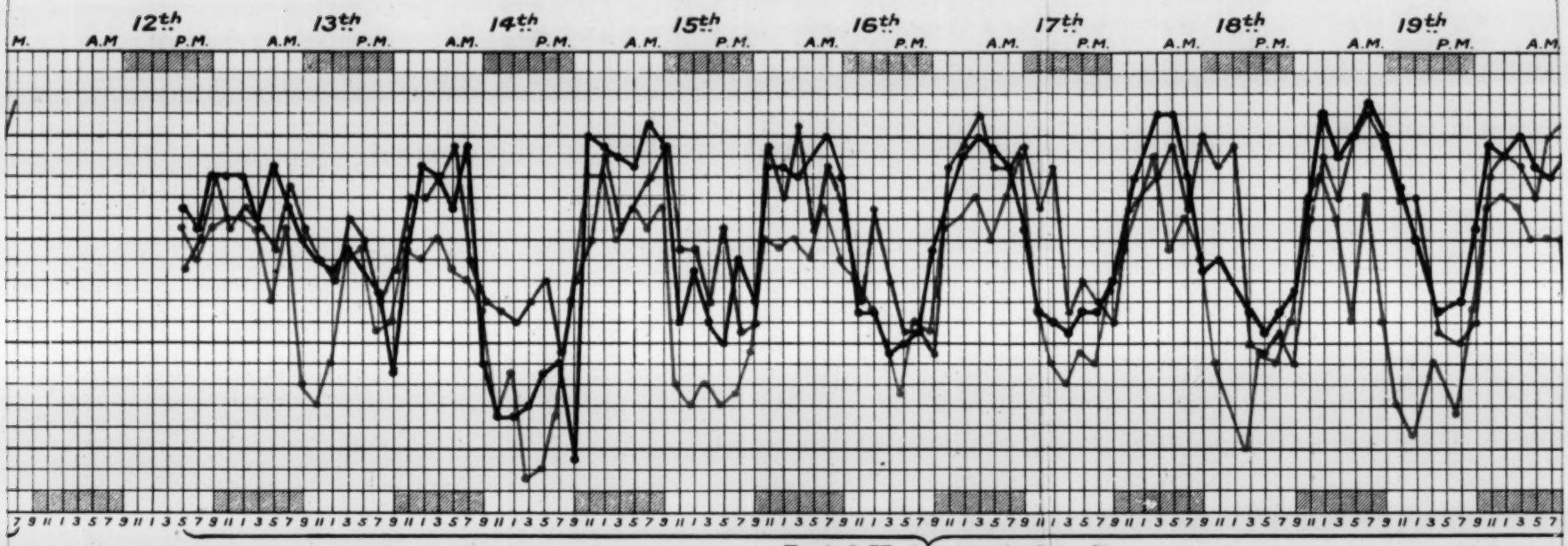


Period I. (normal).

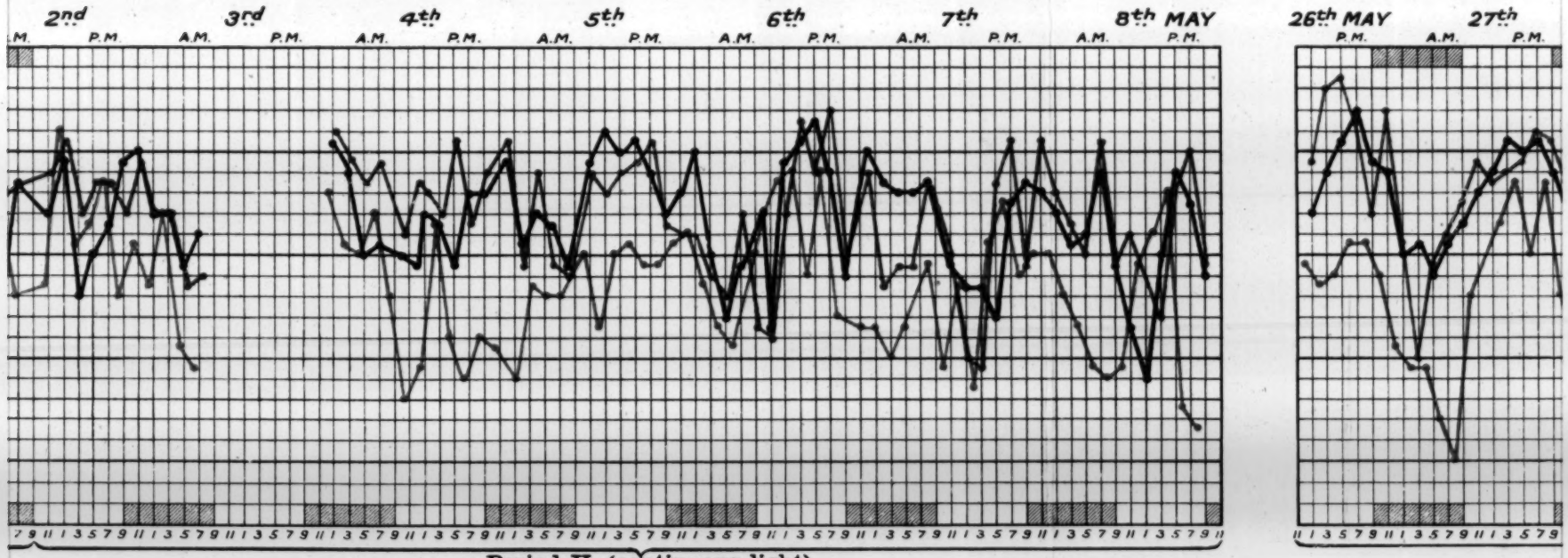


Period IV. (continuous darkness).

Chart I. — Temperature curves obtained from monkeys B.—Macacus rhoesus ♂, Adult—(red line); C.—Macacus rhoesus ♀, Immature—(blue line); D.—M
The shaded bands at the bottom of the Chart indicate the normal periods of rest as previously determined, while the periods of darkness artif
Observe that the apices of the curves are found in the unshaded parts at the top (periods of activity) whether these correspond with the natu
The black band at the top in period VI. indicates the time during which the monkeys were not fed.



Period II. (reversed—9 to 9).

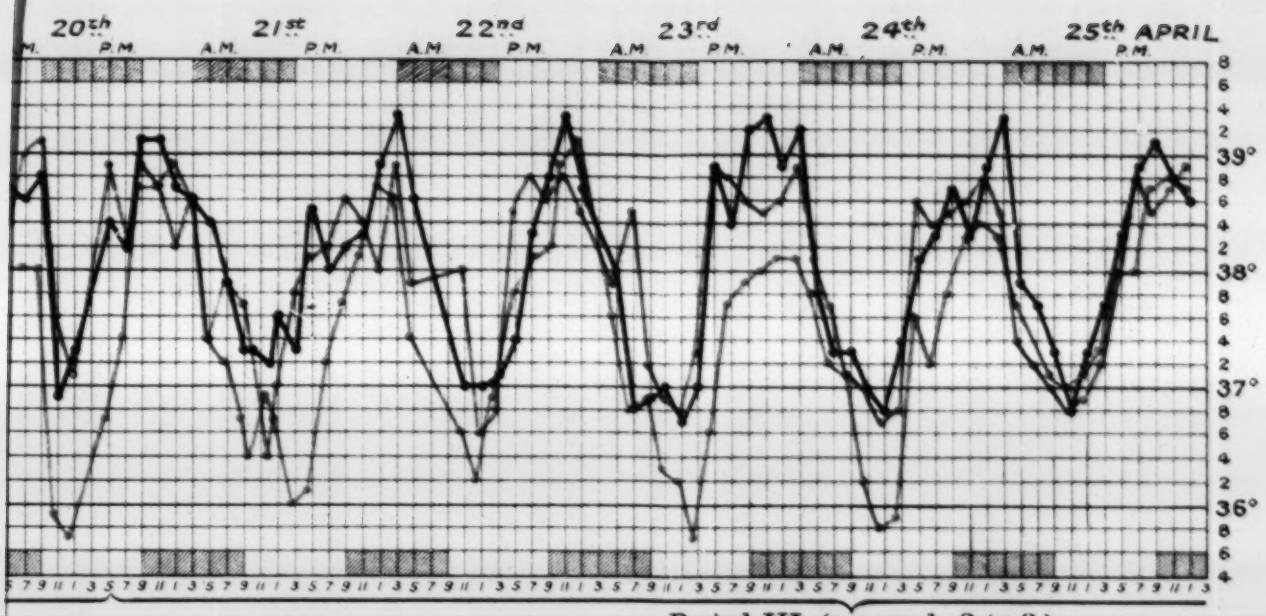


Period V. (continuous light).

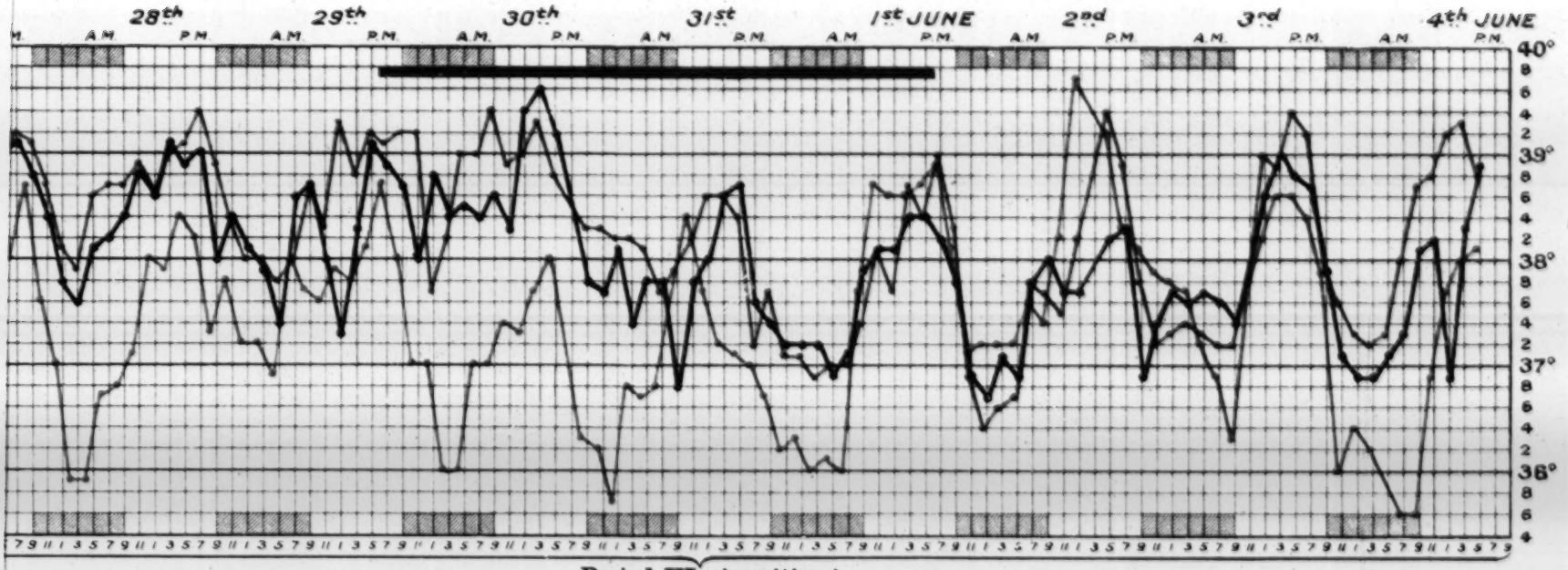
line); D.—Macacus cyanomolgus ♀, Aged—(green line).

arkness artificially imposed upon the monkeys are represented by those at the top.

ith the natural day or not.



Period III. (reversed—3 to 3.)



Period VI. (inanition.)

A RITCHIE & SON, EDIN.

V.—Distribution of the Cells in the Intermedio-Lateral Tract of the Spinal Cord.

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The term *intermedio-lateral tract* was introduced in 1859 (*Phil. Trans.*, 1859, p. 445) by LOCKHART CLARKE to designate a tract or column of nerve cells in the spinal cord, which he had previously described in 1851 (*Phil. Trans.*, 1851, ii. p. 613) as occupying that portion of the lateral margin of the grey matter which is intermediate between the anterior and posterior cornua. According to CLARKE's original account, the column in question was very transparent in appearance, and resembled somewhat the substantia gelatinosa of the posterior horn. It was found in the upper part of the lumbar enlargement, extended upwards through the dorsal region, where it distinctly increased in size, to the lower part of the cervical enlargement. Here it disappeared almost entirely. In the upper cervical region it was again seen, and could be traced upwards into the medulla oblongata, where, in the space immediately behind the central canal, it blended with its fellow of the opposite side. In the more complete account of the tract published in 1859 (p. 446), its component cells are described as in part oval, fusiform, pyriform, or triangular, and as being smaller and more uniform in size than those of the anterior cornua. In the mid-dorsal region, where they are least numerous, they are found only near the lateral margin of the grey matter, with the exception of some cells which lie among the white fibres beyond the margin of the grey substance. In the upper dorsal region the tract is larger, and not only projects further outwards into the lateral column of the white fibres, but also tapers inwards across the grey substance, almost to the front of Clarke's column. In the cervical enlargement it gradually disappears, although it seems to contain, in part at least, a few scattered cells resembling those of the intermedio-lateral tract of the dorsal region. In the upper cervical region, as already stated, it is again seen occupying a lateral horn similar to that found in the dorsal region. It is composed of the same kind of cells, and can be followed up into the medulla, where it is said to give origin to some of the fibres of the vagus and the spinal accessory.

WALDEYER, GASKELL, SHERRINGTON, MOTT, and others have drawn attention to the probability that the dorsal vagus nucleus of the medulla belongs to the same system as the intermedio-lateral tract.

GASKELL has shown that sympathetic fibres pass out with the second and third sacral roots, and SHERRINGTON, without giving a definite opinion on the subject, has suggested that the cells which appear in the sacral region as a lateral horn probably belong to the intermedio-lateral tract system.

As the present paper concerns itself, however, purely with the tract as it is found in the dorsal, lower cervical, and upper lumbar regions, the question raised in the two previous paragraphs as regards its distribution in the upper cervical and lower sacral regions will not be further referred to.

The majority of anatomists who have written on the subject since CLARKE's original papers appeared have regarded the intermedio-lateral tract as being synonymous with the cells of the lateral horn. This view is not exactly in accordance with the definition or the description and figures of CLARKE, an examination of which shows that, as already stated, he was aware that the tract passed beyond the limits of the lateral horn, both backwards along the margin of the grey matter and also inwards towards the column of CLARKE (*Phil. Trans.*, 1859, p. 446, Pl. XX. figs. 2 and 4; also Pl. XXI. figs. 3, 5 and 6).

WALDEYER, in his work on the Spinal Cord of the Gorilla (*Abth. der König. Akad. der Wissenschaft*, Berlin, 1898), has subjected the intermedio-lateral tract to a careful examination, and has done more than any other writer since CLARKE to advance our knowledge and broaden our views with regard to the character and distribution of its cells. He makes it clear that the cells of the tract are not limited to the lateral horn, but that also *at the margin of the grey matter near the formatio reticularis there are found cells identical with those in the lateral horn.* These are, in his opinion, therefore, component parts of the intermedio-lateral tract. He is further of opinion that the tract does not, as CLARKE thought, disappear in the cervical and lumbar enlargements, but that *it is found throughout the whole length of the cord. While he admits that it may disappear as a lateral horn in the cervical enlargement, he maintains that it is continued upwards as the cells of the formatio reticularis.* He is further in agreement with KRAUSE in thinking that the lateral horn of the dorsal region is not identical with the lateral projection of the anterior cornua in the cervical and lumbar enlargements, and that the cells of the intermedio-lateral tract are not mere transformations or modifications (SCHWALBE, ERB, OBERSTEINER, QUAIN) of the cells in the lateral part of the anterior cornua, but are of altogether independent origin and nature.

SHERRINGTON (*Journ. Physiol.*, 1892, p. 698), with reference to these conclusions of WALDEYER's, says: "WALDEYER, in his description of the grouping of the cells in the cord of the gorilla, says that the lateral horn cells are found throughout the cord in all its segments, including those of the cervical and lumbar enlargements. He divides the ganglion cells of the cord into as many as fourteen definite groups, attaching to each a name, but treats the cells of the lateral reticular formation and those of the lateral horn as one group (Mittelzellen). When he says that the cells of the lateral horn are present in, for instance, the eighth and seventh cervical segments, his meaning is that there are cells in the reticular formation at that level which he considers are cells of the lateral horn, although that horn can no longer with certainty be recognised. But in regions where the lateral horn exists there are cells in the lateral reticular formation as well as in the lateral horn, and the assumption that the cells of the lateral reticular formation, although somewhat similar to the cells of the lateral horn, are identical with

them, or are their equivalents, is a somewhat insecure foundation on which to rest the statement that the cells of the lateral horn are present in a region where there is no other evidence of them beyond cells in the lateral reticular formation."

SHERRINGTON has not been able to trace lateral horn cells higher than the middle of the superficial origin of the eighth cervical nerve. In Rhesus he has not found them above the surface origin of the first thoracic root. The lower extremity of the tract he finds to correspond to the surface origin of the fourth lumbar nerve. This would correspond to the third lumbar segment in man. As regards the longitudinal distribution or grouping of the cells in the intermedio-lateral tract, WALDEYER notes, on p. 19, that they lie close together, and that they may be arranged in groups or clusters separated by interspaces in which there are no cells. "Bezüglich ihrer Anordnung ist zu sagen dass sie gewöhnlich dicht zusammengedrängt liegen. Selbst wenn keine grössere Zahl dieser Zellen vorhanden ist liegen sie häufig zu zweien, dreien oder vieren nahe beisammen ; zwischen diesen einzelnen kleinen Gruppen können dann allerdings grössere Zwischenräume vorhanden sein. Jedenfalls bilden diese Zellen stets eine besondere Formation im Rückenmarke."

This arrangement of the cells in groups or clusters has also been referred to by AINSLIE HOLLIS, in the *Journal of Anatomy and Physiology*, vol. xvii., 1883, p. 63 : "The (intermedio-lateral) tract consists of clusters of small (mostly pyriform) cells arranged linearly, and dissociated from each other, and from the column of sparsely scattered giant cells to which they are contiguous, by a delicate fibrillar stroma of synectic tissue. In the mid-dorsal region I have observed two adjacent columns of these cell-clusters." Again, at p. 520, referring to "the vesicular columns of CLARKE and the tractus intermedio-lateralis," he says that "in certain parts of the cord they are found closely congregated in cell-nests."

MOTT (*Brain*, 1890, p. 444) says: "The cells of the intermedio-lateral tract are found throughout the dorsal region. The cells are bi-polar, and in vertical sections they are often seen to exist as little groups or nests of vesicular cells, from eight to twelve in number."

ONUF and COLLINS (*Sympathetic Nervous System*, 1900, p. 140), in describing the cells of the lateral horn, say : "The group is represented by a very pure type in the lower dorsal region. In longitudinal sections it does not appear in the form of a continuous column, but segmented, in the form of cell-nests distributed at intervals."

ARGUTINSKY, a pupil of WALDEYER'S, in a valuable paper in vol. xlviii. of the *Archiv für mikroskopische Anatomie* (1897), "Ueber eine regelmässige Gliederung in der grauen Substanz des Rückenmarks beim Neugeborenen und über die Mittelzellen," in which he for the first time describes a segmentation of the "Mittelzellen" of WALDEYER, refers, on p. 514, to a somewhat similar mode of grouping of the cells of the intermedio-lateral tract. He says: "Verfolgt man die Seitenhornzellsäule in einer Serie von Sagittallängsschnitten, vom Seitenstrang zur Mittellinie vorschreitend, so sieht man, wenn man dem Seitenhorn sich nähert, erst eine oder ein paar Längsreihen

von einzelnen Zellen, wie Perlschnüre, zwischen den Längsfasern des Seitenstrangs angeordnet. Dann werden diese einzelligen Reihen zahlreicher. . . . Die einzelnen Glieder der Seitenhornzellsäulen sind zwar grösser, als die Mittelzellengruppen, doch sind die Abstände zwischen den Centren zweier Gruppen sowohl bei den Seitenhornzellen, wie den Mittelzellen gleich so dass beide Zellsäulen Ketten bilden, welche gleich viele und gleiche gelagerte Glieder besitzen." A first perusal of this paper might leave the impression that the segmentation of the middle cells had been confounded with that of the posterior part of the intermedio-lateral tract, but ARGUTINSKY has stated, in a most categorical manner, that the two systems of cells are distinct in form and in position, although he admits that they may approach each other very nearly. An examination of the text of WALDEYER's paper and his plates and diagrams of sections from man and the gorilla shows also that the "Mittelzellen" and the intermedio-lateral tract are two independent systems. WALDEYER has personally confirmed this statement, after examining my preparations. It is evident, therefore, that ARGUTINSKY has noted a segmental grouping of the cells of the intermedio-lateral tract.

HERRING (*Journ. Physiol.*, 1903, p. 285) says: "The cells of the lateral horn vary in size considerably. They occur in groups, and in some sections may be absent from the lateral horn altogether."

The above references and quotations indicate that several observers had noted the fact that the intermedio-lateral tract is not a continuous column of cells, but that its cells are arranged more or less in groups. So far as I am aware, however, no exhaustive examination has up to the present time been made of the distribution of the cells in the tract. This want it is the object of the present communication to supply.

In 1903, while engaged in the study, by means of serial sections, of the distribution of the large motor cells and of the smaller and more faintly staining polygonal cells in the cervical enlargement of the spinal cord, I was struck with the appearance in the first dorsal segment, and to a lesser extent in the lower part of the eighth cervical segment, of special groups of cells differing in character and in arrangement from the above-mentioned large motor and small polygonal cells. These groups were situated within or adjacent to the posterior border of the lateral portion of the anterior horn. Under a low power of the microscope they readily attracted the eye, owing to the facts that they were closely grouped together, that they were fusiform in outline, and that their long axes for the most part ran in the same direction. These features, and the fact that they stained almost as deeply as the large motor cells, rendered them exceedingly conspicuous. In the eighth cervical and in the upper part of the first dorsal segments they were found entirely in the white matter either at a little distance from or quite close to the anterior cornu. In either case they lay behind the junction of the outer and the middle thirds of its posterior border, or behind the outer third. In the lower part of the first dorsal segment this position was departed from, and they gradually encroached forwards upon the grey matter and at the same time passed outwards towards the lateral margin of the anterior cornu. To speak more accurately, this relative change

of position was due to the recession and shrinkage of the anterior cornu, owing to the diminution in the number of its large motor cells which takes place here. Another feature which characterised these cells—a feature which led to this special investigation—was this, viz., that they were not found in each of the successive serial sections. It was noted that they would suddenly appear as a small group of two or three cells, and that in succeeding sections they rapidly rose to a maximum. They then almost as rapidly diminished in number, and thereafter disappeared entirely from the field throughout a varying number of sections. This phenomenon repeated itself eight or nine times in the first dorsal segment. As the lower end of this segment was approached, the groups became larger and the intervals between them shorter. On tracing the groups downwards into the lower part of the first and through the second dorsal segment, it was evident that the cells forming them were the same as those which are there recognised as the intermedio-lateral tract. The examination of the eighth cervical and first dorsal segments of a second, and of corresponding segments of a third cord demonstrated that this arrangement of the cells in groups separated from each other by distinct intervals was a constant phenomenon, and not an individual peculiarity of the cord first examined. The question then presented itself—Was this arrangement of the cells in groups limited to the two segments in question (C. 8 and D. 1), or did it extend throughout the whole of the length of the intermedio-lateral tract, and if so, was there, as had been established in the case of the motor cells in the cervical and lumbo-sacral regions, any grouping of the cells which might be regarded as characteristic of each segment in which it was found? In order to determine these points the third cord was examined from the upper part of the cervical enlargement to its lower extremity. This cord, obtained from an individual presumably free from any disease of the nervous system, was hardened in formalin and divided into root segments according to the manner employed in preparing the sections for my "Topographical Atlas of the Spinal Cord," sections as nearly as possible at right angles to the median plane of the cord being made below the lowest fibres of each nerve root. The segments so obtained were further hardened in alcohol, embedded in celloidin, and divided into serial sections of uniform thickness. The sections were stained with toluidin blue or with Unna's polychrome blue, with FORD ROBERTSON'S precautions to prevent decolorisation.* Special means were taken to ensure that the corresponding sides of each section had a corresponding position on the slide, so that on this ground there should be no error in the enumeration of the cells on either side, or in comparison of those of one side with those of the other. Some 7000 sections in all were examined. Of these more than 5000 contained cells of the intermedio-lateral tract. These cells, as found on both sides of the cord, were carefully counted independently by four different observers.† The

* This group of stains is specially suitable, as it singles out the nerve cells and throws them into such relief that they are more easily enumerated than if stained by any other method.

† I take this opportunity of acknowledging my indebtedness to Dr MACFIE CAMPBELL, Carnegie Research Scholar, for assistance in preparing the sections and enumerating the cells; to Dr HARVEY PIRIE, B.Sc., for assistance in enumerating cells; and to my son, A. NINIAN BRUCE, for making the drawings for the figures 1–24.

results arrived at were then compared, and any discrepancies were considered and corrected. In this way greater precision as to the lateral boundaries of the tract and the number of its cells was arrived at than would have been possible for a single observer. The results of the finally corrected enumeration were then plotted graphically on the diagram (Pl. I.). I am satisfied that the numbers are in no case excessive.*

In C. 8 and D. 1, and in D. 2 (upper part), the enumeration of the cells of the intermedio-lateral tract presented no particular difficulty. They formed very compact and sharply circumscribed clusters, and their form and arrangement were so different from those of any of the motor cells of the anterior cornu which were adjacent to them that there was not the slightest difficulty in distinguishing the one from the other. This was true in C. 8 and upper D. 1, where the cells lay behind the lateral part of the anterior cornu, and in lower D. 1 and upper D. 2, where they formed a group limited to the apex of the lateral horn proper. In the enumeration of the cells which lay between the lower part of D. 2 and the lower extremity of the tract, two difficulties were met with—one from the frequent absence of definition of the inner margin and the other from the want of precise information as to the posterior limit of the tract. On the inner aspect of the tract there were frequently seen small polygonal cells, sometimes in fairly compact groups, sometimes as more scattered cells. These, which evidently corresponded to the "Mittelzellen" of WALDEYER, sometimes approached very closely to the cells of the intermedio-lateral tract, but with care they could generally be separated from the latter. After a short training in the enumeration of the cells, there was generally a close agreement between the various observers as to the limits of the intermedio-lateral tract and the Mittelzellen. There seemed little doubt that the Mittelzellen did not represent a part of the intermedio-lateral tract.

The second difficulty, that of determining the posterior limit, was a much more serious one. It arose from the fact that groups of cells of a character practically identical with that of those found at the tip of the lateral horn were situated at the margin of the grey matter, either underlying or partially entering into the formatio reticularis, and extending as far back as the level of the posterior margin of Clarke's column, or even further. In certain sections this series of cells (which will be referred to in future as the *reticular cells*, from their relation to the formatio reticularis) seemed absolutely distinct and separate from that situated at the apex of the lateral horn (the *apical cells*). In consecutive sections it was found that the interval between the two sets of cells lessened gradually until they came to approach each other closely, and even to fuse so completely that it became impossible to distinguish the one from the other. It was also observed that, almost without exception, the number of the apical cells and that of the reticular cells rose and fell together; when the one reached its maximum so did the other, and *vice versa*. At first I was inclined (*Rev. Neurol. and*

* At the upper and lower limits of each segment one or more sections were generally lost, owing to causes which could hardly be avoided. In D. 11 some fifty sections were rendered useless owing to an accident from a fire which occurred in the laboratory when the work was in progress. With these exceptions the sections were practically continuous.

Psychiat., vol. ii. p. 582) to regard the reticular series of cells as distinct from the apical one, and consequently endeavoured to enumerate them independently of each other. This was, in those sections where the two sets of cells were not in contact, a simple matter; but in a great many sections it was quite impossible to trace any line of demarcation between the two, so closely were they fused. On making a second enumeration so as to include the reticular cells along with those at the apex of the lateral horn, the remarkable fact became evident that the effect on the groups plotted out in the chart was simply this, that the maxima were increased and the minima remained unaltered. A further careful examination of the relation of the two rows of cells throughout the dorsal region and the first lumbar segment showed that in following them through a series of sections it was always possible to trace them into intimate connection with each other. The posterior or reticular cells were therefore included in and enumerated as an integral part of the intermedio-lateral tract. This opinion was not arrived at without full consideration, and it was satisfactory to find on a subsequent study of WALDEYER's work on the spinal cord of the gorilla that it had the support of his authority.

The results of the examination of each segment may now be stated.

Eighth Cervical Segment.—This was divided into 280 sections. Its intermedio-lateral tract contains 429 cells on the right and 595 on the left side. These are distributed as follows (see graph): The upper fourth part of the segment is practically devoid of cells, there being only one cell on the right side (situated in section 68), and on the left side one each in sections 67 and 69.

The second fourth contains three small groups of cells, separated by wide intervals. The number of cells seen in any one section never exceeds four, and the number in the largest group (R. 108-119) is thirty-one.

The third fourth contains on the right side three small groups. If the cells on the left side of sections 144–162 inclusive be regarded as belonging to one group, and those from section 173 to 187 as comprising another, there are two small groups and the beginning of a third on the left side.

The lowest fourth contains by far the largest number of cells in the segment. In the right side these are distributed in four and on the left in three groups. The largest of these is on the left side. It extends from section 192 to 227, and contains 286 cells. The preponderance of the cells on the left over those on the right is due mainly to this nucleus.

Throughout the whole segment the cells of the intermedio-lateral tract are situated in the white matter. They are all "outlying," as SHERRINGTON has termed them, although they vary somewhat in their distance from the grey matter. They are connected with this, however, by strands of connective tissue. Their long axes correspond to the direction of these strands, and for the most part run parallel to the adjacent border of the grey matter, being thus oblique outwards from behind forwards.

No reticular group is seen. Such cells as are situated behind Clarke's column and

the formatio reticularis are of the small polygonal type characteristic of the "Mittelzellen" of WALDEYER.

Note.—It may be stated here that no cells which could be definitely considered to belong either to the apical or to the reticular portions of the intermedio-lateral tract were found in any segment of the cervical enlargement above the limit indicated in C. 8. Any group of cells that was seen in the grey matter between the anterior and posterior cornua and internal to the formatio reticularis belonged evidently to the "Mittelzellen," and not to the intermedio-lateral tract.

First Dorsal Segment.—This was divided into 202 sections. Its intermedio-lateral tract contains 1720 cells on the right and 1837 on the left side. These are distributed in sharply defined groups, with distinct, and, as a rule, wide intervals between

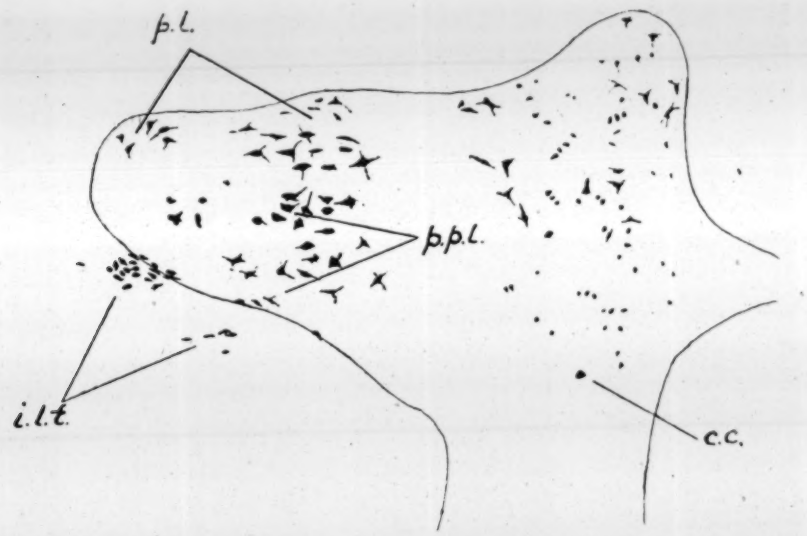

FIG. 1 (C. 8, 247, L.).—Two groups of cells belonging to the intermedio-lateral tract are seen. Both are outside the grey matter of the lateral part of the anterior cornu. The larger of the two is a group of closely aggregated cells, close to the margin of the horn, and having their long axes pointing outwards and somewhat forwards. In the smaller group, which is further removed from the horn, the cells are more irregularly placed, but their long axes on the whole point outwards.

them (see graph, D. 1). As in C. 8, the largest cell-groups are situated at the lower extremity of the segment. With one exception (the fourth on the left) the groups resemble each other in that the number of their cells rapidly rises to a maximum and then almost equally rapidly falls away to zero. The graph thus presents the appearance of a succession of spires. Of these there are ten (or possibly only nine) on the right and eight on the left side. While there is a close resemblance of form between

[The figures in the text represent transverse sections of certain of the cells from the various segments examined. The position in the segment is indicated thus: C. 8, 247 means the two hundred and forty-seventh section of the eighth cervical segment. R. and L. indicate right and left sides respectively.

a. m. Anterior median group of motor cells.
a. l. Antero-lateral ,, ,,
p. l. Postero-lateral ,, ,,
p. p. l. Post-postero-lateral ,, ,,
c. C. Clarke's vesicular column of cells.
i. l. t. Intermedio-lateral tract.
m. c. The middle cells of anterior cornua: the Mittelzellen of WALDEYER.]

the cell-groups on the two sides, this resemblance does not amount to a perfect symmetry. The largest group (the lowest on the right side) contains 578 cells, and the largest number of cells in any one section is 58.

At the upper extremity of the segment the intermedio-lateral tract is distributed on the posterior border of the anterior cornu, a little internal to its lateral tip; but, with the progressive diminution of the number of large motor cells, its position relative to these continues to shift outwards until, near the lower end of the segment, it comes to lie at the apex of what is now the lateral horn proper. The cells in the upper part of the segment lie for the most part within the grey matter, quite close to its margin, but wherever their number undergoes a considerable increase they tend to project outwards

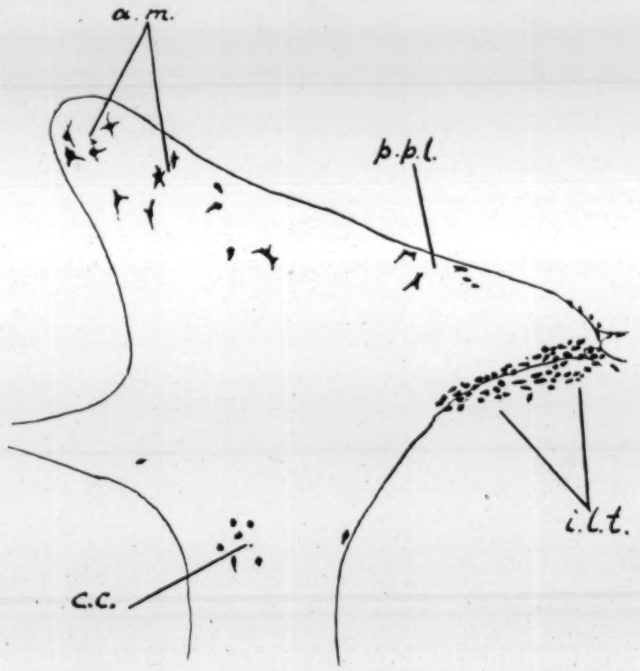

FIG. 2 (D. 1, 175, R.).—The cells of the intermedio-lateral tract form a large group, partly within and partly without the cornu, a few being separated by a distinct interval from the main group. The majority of the cells have their long axes in an oblique direction, and more or less parallel to the posterior margin of the horn.

into the white matter. In some groups the cells are, on the other hand, almost entirely "outlying," or there may be a few outlying cells, while the main mass of the cells is found in the grey matter. In the upper part of the segment the cells are closely aggregated; but at its lower part, where the lateral horn proper is fully constituted, they are less compactly grouped, and tend to spread along the posterior, and, even in some places, also along the anterior border of the horn. This anterior group sometimes becomes separated off from the cells at the tip of the horn. Those on the posterior margin spread further from the apex than the anterior ones, but they do not reach the formatio reticularis. There is no indication of any reticular group in this segment.

The long axes of the cells are in general parallel to the margin of the grey matter, although the outlying cells assume the direction of the strands of connective tissue in which they lie.

Second Dorsal Segment.—This segment contained 228 sections. The cells of its intermedio-lateral tract number 3635 on the right and 3931 on the left side. The groups of cells, as represented in the graph, retain their spire-like appearance, the rise and fall of the cells in each group being still rapid. The spires are more slender on the right side. The intervals separating them are shorter than in D. 1, and not always complete. The groups are wider here than in D. 1, each one being spread over a larger number of sections, especially on the left side. They number 12 to 15 on the right, and 11 or 12 on the left. As in D. 1, though there is a general resemblance of form on the two sides, the symmetry is not quite complete. The largest number of cells in any one section is 58.

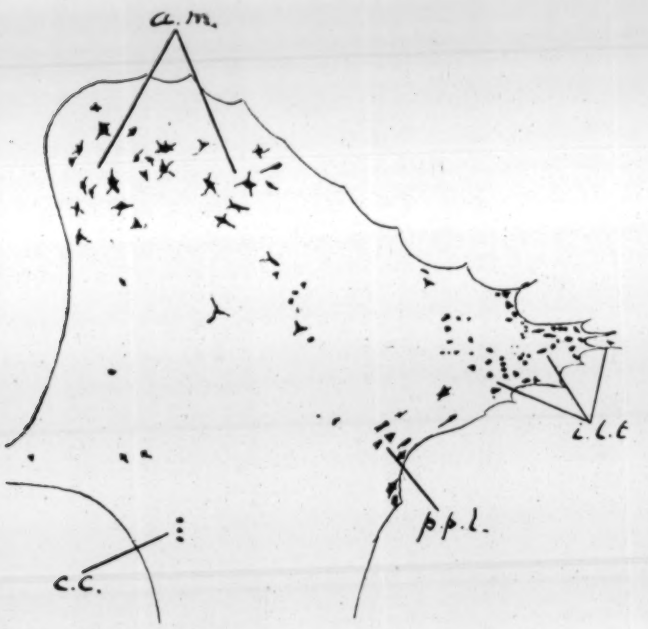

FIG. 3 (D. 2, 4, R.).—The cells of the intermedio-lateral tract are now at the apex of the lateral horn proper. The long axes of the cells have no constant direction, and the cells are not so closely compacted as in the previous figure. A small aberrant group of post-postero-lateral cells (*p. p. l.*) is seen near the re-entrant angle between the lateral and the posterior cornua.

FIG. 4 (D. 2, 169, L.).—This figure is taken from a section through that portion of the tract in which the reticular cells first appear. Their position at the re-entrant angle of the grey matter and their partial separation by a slight interval from the apical cells is seen.

As regards their distribution, the cells sometimes form a triangular group, the apex of which occupies the tip of the lateral horn; sometimes they stretch as a band along the posterior margin of the lateral horn. There are a few outlying cells in the white matter (fig. 3).

In the lower half of the segment, at section 165 on the left side, we have the first definite appearance of the *reticular* group (fig. 4). At its commencement, which is abrupt, it is apparently a separate group, but two sections below that at which it is first observed it becomes continuous with the original group of intermedio-lateral cells, and is hardly distinguishable from it in so far as size of cells is concerned. This reticular group dies out again in section 174 on the left side. On the right side (fig. 5) it appears first in section 177, then gradually increases in size, spreads back along

the posterior border as far as the posterior limit of Clarke's column, and disappears in section 186. It reappears as a small group on both sides in section 199, and again on the right from section 204 to section 216.

As regards the position of the cells, when these lie at the apex of the horn in a triangular group, their long axes show no constant direction, but when they extend in bands along the posterior margin, their long axes run parellel to the border (figs. 3 and 4).

In the upper part of this segment a few aberrant cells of the post-postero-lateral group are found among and internal to the cells of the intermedio-lateral tract (fig. 3).

A fact which is worthy of note as regards this segment is the remarkable vascularity

FIG. 5 (D. 2, 181, R.).—This is drawn from one of the sections which show the first appearance of the reticular cells on the right side. The cells underlying the formatio reticularis are few in number, but there is a large group at the base of the lateral horn, and separated from the apical cells by a slight interval.

of the intermedio-lateral tract, vessels passing into it directly from the lateral periphery of the cord.

Third Dorsal Segment.—This segment was divided into 276 sections, in which the cells of its intermedio-lateral tract number 7471 on the right side and 7297 on the left. The graph of this segment presents a remarkable contrast to those of D. 2 and D. 4, in both of which the groups of cells are represented as slender spires, separated from each other by distinct intervals which are almost devoid of cells. In D. 3, on the other hand, with one or two exceptions about the centre of the right side, the groups of cells are arranged in broader masses, with less indication of a spire-like arrangement. The masses are separated by less distinct intervals, in which there always remain a considerable number of cells. The intervals are so indistinct that it is difficult to be certain of the number of groups on the right side. Probably there are fifteen. On the left side there appear to be thirteen groups, and there may have been fourteen, as some sections at the lower end of the segment (owing to an accident in preparation) do not show the grey matter on the left side. This great increment of the cells is due to the

large number both in the apical and in the reticular groups. The reticular group is generally present at the re-entering angle between the anterior and the posterior cornua. It is either continuous with the apical group or separated from it by a distinct interval. Its cells are sometimes arranged in a triangle with its apex inwards, and its base towards the formatio reticularis. Its cells lie generally with their long axis pointing forwards and inwards. The apical group either lies at the tip of the lateral horn or forms a triangle of considerable size, with its base inwards, and there is a tendency for the cells to extend along the anterior surface of the lateral horn as a special anterior group (D. 3, 74 ; fig. 6). No distinct difference in the size of the cells contained in the apical and reticular groups could be made out.

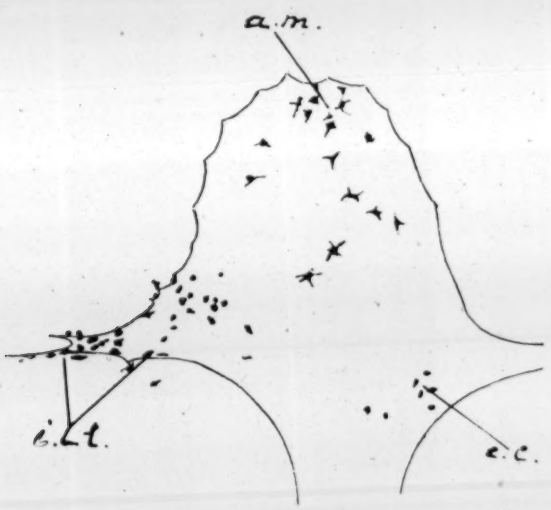

FIG. 6 (D. 3, 74, L.).—This figure shows a large anterior group of cells in the intermedio-lateral tract, the apical cells being few and the reticular ones being unrepresented.

Fourth Dorsal Segment.—This segment was divided into 182 sections, and its intermedio-lateral tract contains 3803 cells on the right side and 3623 on the left. The groups of cells, as represented on the graph, show a return to the spire-like arrangement of D. 2, with this difference, that the spires as a rule are higher than and not quite so slender as in D. 2. The intervals between them are, however, very distinct. There are nine groups on the left and ten on the right side. (An eleventh group at the lower end of the segment is continued into the first group of D. 5, and is therefore not enumerated here.) The greatest number of cells in any one section (149 on the left side) is 82. This is the greatest number found in any one section of the whole intermedio-lateral tract. In this group there is, in fifteen sections, a rise from 5 cells to 82, and then a fall again to 2 cells. In section 149 (fig. 7) the connection and identity of the apical and reticular groups is clearly established. On examining the sections in which this group was found, it is easy to see that where an interval appears between the two sets of cells it is caused merely by the presence of a bundle of nerve fibres, and is not due to any real difference in the nature of these cells. There is no constant difference in the size of the cells in the

two cell-systems, there being a greater disparity in the size of the cells contained in either group than between those of the two individual groups. This association of the two groups, reticular and apical, as will be seen, could be traced throughout all the lower parts of the region in which the two tracts were found. The reticular group occasionally curves inwards in front of Clarke's column (fig. 8, D. 4, 151). The apical sometimes gives off a small anterior group on the anterior aspect of the lateral

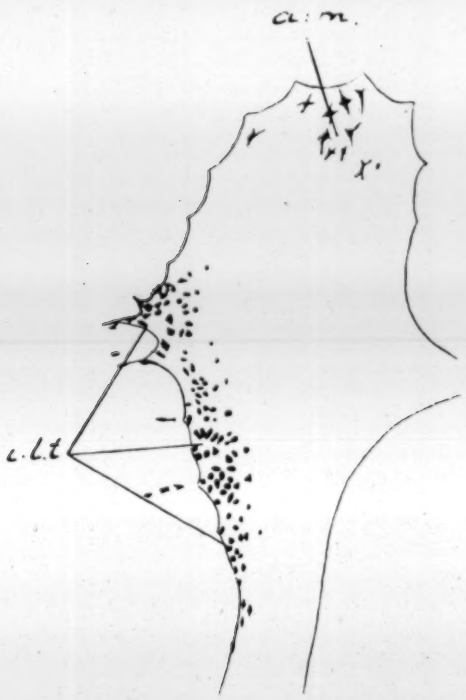

FIG. 7 (D. 4, 149, L.).—In this section the apical and reticular cells form one long continuous group, which extends from a point in front of the tip of the lateral horn to a point much behind the level of Clarke's column. Eighty-two cells were counted in this section. A few of them were situated in the white matter.

FIG. 8 (D. 4, 151, L.).—This figure shows the continuity of the apical and the reticular cells, and also a tendency of the group to extend inwards in front of Clarke's column.

horn. There are a few outlying cells near the tip of the lateral horn, but a greater number in the formatio reticularis.

Fifth Dorsal Segment.—This segment was divided into 350 sections, in which the cells of the intermedio-lateral tract on the right side amount to 7407 and on the left to 7958. The segment shows a remarkable difference between its upper third and its lower two-thirds. In the upper third the groups as represented on the graph continue to show a spire-like character, closely resembling that of D. 4, although of a less slender type, and on the whole with less complete intervals. In the lower two-thirds the spire-like character is less marked. There is a remarkable change in the character of the groups, there being a gradual transition towards the types of D. 6 and D. 7, in which the graph suggests mounds with rounded tops on which are superposed short and slender spires. The intervals between the groups in the lower two-thirds are distinctly less than in the upper third. The number of the

groups on the right side is difficult to determine; probably there are fourteen. On the left side there are fourteen fairly distinct groups. This transition in the character of the graph is associated with a decrease in the number of cells in the apical and a rise in that of the reticular series. The latter tends in the lower two-thirds of the segment to assume a distinct wedge-shape, with its apex pointing inwards and forwards in front of Clarke's column (fig. 9, D. 5, 238). In some parts the cells of the reticular group appear slightly smaller in size than those of the apical group, but this relationship is not constant. The outlying cells are rather numerous, especially near the tip of the

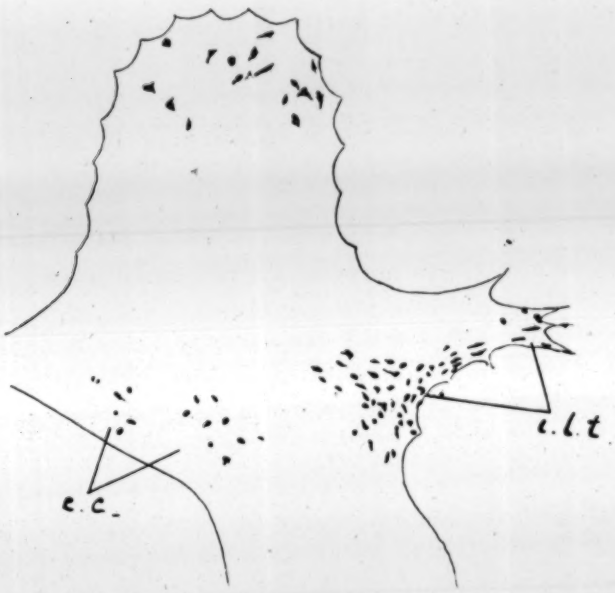

FIG. 9 (D. 5, 238, R.).—The reticular cells form a large group, of a wedge-shape, with its apex pointing inwards in front of Clarke's column and its base situated on the formatio reticularis. The apical cells are here relatively few in number.

lateral horn. The oscillations in the number of cells are greater in the reticular than in the apical group.

Sixth Dorsal Segment.—This segment was divided into 438 sections, the intermedio-lateral tract consisting on the right of 8030 and on the left of 8105 cells. Fifteen groups were counted in each side. The graphic chart of these shows that the change begun in D. 5 is continued throughout the segment, the lower half bearing a close resemblance to the appearance found in D. 7. There are no high ascents, and no complete intervals between the mound-like elevations. In section 152 on the left side 58 cells were counted—the maximum number in the segment. In most of the other sections the maximum number lay between 30 and 40. In this segment is the only instance of an exception to the rule that the numbers of the apical and reticular groups rise and fall simultaneously. In a cluster which lies between sections 270 and 340 the apical group reaches its maximum while the reticular group is at its minimum. Throughout the segment the reticular group as a whole is considerably smaller than it is in D. 5. Its cells are more loosely scattered, with less of a triangular arrangement,

and are more separated by bundles of white fibres than in D. 5 (fig. 10, D. 6, 253 R.). The cells in the apical group are frequently of a large size, measuring 40–50 μ. The vascularity of the group is very remarkable, and it is noticed that the main supply comes from the vessels of the periphery of the cord.

Seventh Dorsal Segment.—This segment was divided into 518 sections. The intermedio-lateral tract on the right side contains 8282 and on the left 8739 cells. Sixteen groups can be counted on each side, and they present a very uniform character throughout the segment. They are rather more distinctly demarcated on the right than on the left side. They present the mound-like appearance found in the lower half of D. 6, with rounded tops, but with less tendency on the whole to the formation of small superposed spires. The maximum number of cells is generally between 30 and

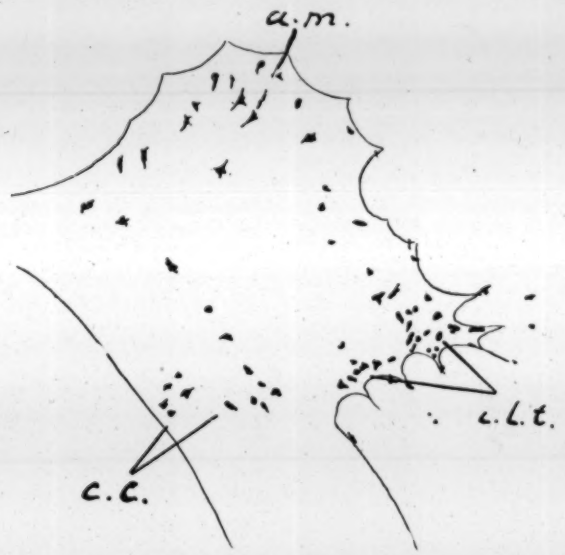

FIG. 10 (D. 6, 253, R.).—The reticular cells are widely scattered, are fewer in number, and have no triangular outline. The apical group contains cells of large size.

40, and the minimum usually under 10. The largest number of cells in this segment is 43 (in section 368 on the right side). There are no complete intervals between the groups. Although the graphs are fairly similar on the two sides, there is a marked difference in the form of their lateral horns. On the right side, in the lower part of the segment, the lateral horn remains as a distinct spike, whereas on the left side it is almost entirely absent, being limited to a slight rounded prominence (fig. 11, D. 7, 151). The reticular group forms a less distinct feature than the apical one. It is difficult to delimit, especially on the inner side. It is either continuous with or separated from the apical group. The apical group is either fairly compact or its cells are more widely scattered. In both groups the cells are relatively large, presenting frequently a close resemblance in size to the motor cells of the anterior cornua (fig. 12, D. 7, 316). Their exact measurements are 40 μ to 60 μ.

Eighth Dorsal Segment.—This segment was divided into 430 sections. The intermedio-lateral tract contains on the right 5943 cells and on the left side 6223. The graph is, on the whole, similar to that of D. 7. The groups are somewhat more definitely

marked off from each other, but there is less difference between the maxima and the minima. The average maximum number of cells is the lowest in the whole of the intermedio-lateral tract, amounting generally to between 20 and 30 cells, the highest recorded being 41. The minima are generally under 10. The groups are more distinct on the right than on the left side, and there are 11 on the right and 13 or 14 on the left (see graph). The lateral horn has only a slight indication of a pointed apex. When this is present it is generally on a level with Clarke's column. The reticular group is similar to that found in D. 7, as its cells are scattered and badly marked off from those on its inner aspect. It frequently extends backwards behind Clarke's column (fig. 13 and fig. 14, D. 8, 112 and 370), and it contains a considerable number of outlying cells in the formatio reticularis. There are a few outlying cells in the neighbourhood of the apical group (fig. 13, D. 8, 112). The cells vary in size.

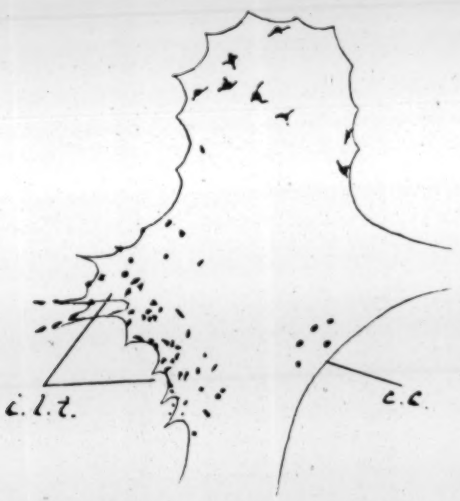

FIG. 11 (D. 7, 137, L.).—The reticular and apical cells are loosely aggregated, not sharply bounded on the inner side. The lateral horn is less prominent than at higher levels.

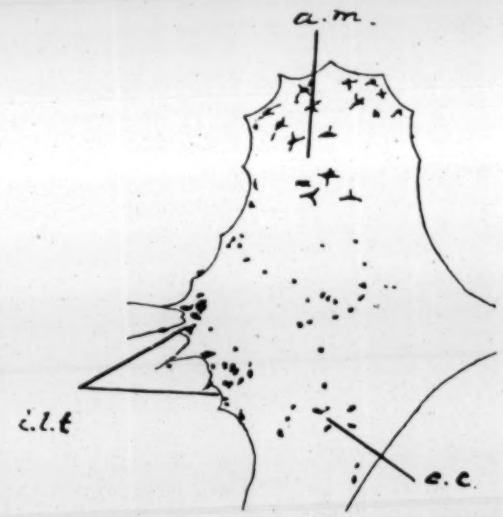

FIG. 12 (D. 7, 316, L.).—The lateral horn is now a mere rounded prominence. There are large cells in apical and reticular groups; these are shown in the anterior part of the apical group, and one in the reticular group.

Some very large multi-polar cells are found in the apical group, and there is a tendency to an admixture of small rounded with medium-sized cells in the reticular group. As in D. 7, the vascularity of the apical group is remarkable, and the supply appears to come mainly direct from the lateral periphery of the cord.

Ninth Dorsal Segment.—This segment was divided into 568 sections. The intermedio-lateral tract on the right side consists of 8987 and on the left of 9011 cells. The graph is similar to that of D. 8, except in the lower third, where there is a slight tendency on the right side to the reappearance of a spire-like arrangement. The cell clusters are somewhat less distinct from each other than in D. 8, the minimum number of cells in the intervals between them seldom falling below 10. The average maximum number of cells in the clusters is about 40, the largest number being 56 on the right side. On the left side the average maximum is about 30, and the largest number is 41. There are 18 clusters on the right side, and on the left either 18 or 20.

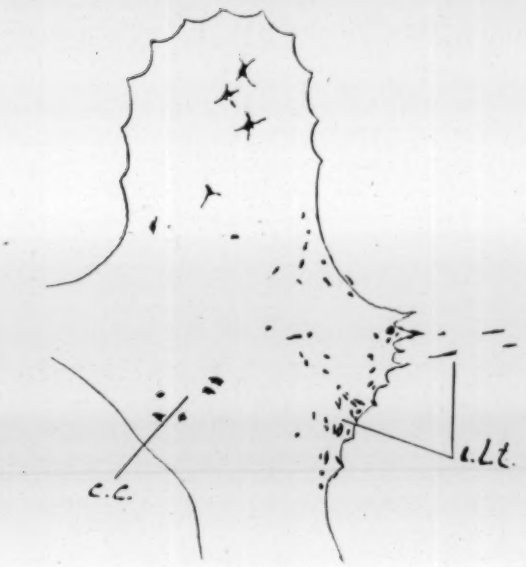

FIG. 13 (D. 8, 112, R.).—The reticular group of cells extends backwards behind Clarke's column. It is indefinitely bounded on its inner side. The apical group is small and shows several distinct outlying cells.

FIG. 14 (D. 8, 370, L.).—The apex of the lateral horn is at a level posterior to the central canal. The reticular cells lie almost entirely behind the level of the column of Clarke. The reticular and apical groups are almost continuous, and they are indefinitely bounded on their inner side. The reticular cells form a sort of wedge which points towards the front of the column of Clarke.

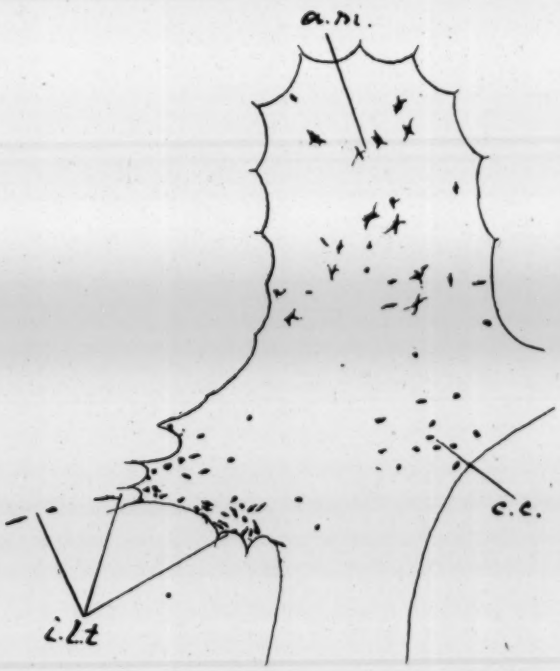

FIG. 15 (D. 9, 168, L.).—The lateral horn with its bluntly pointed apex lies behind the equator of Clarke's column. The altered shape of the horn, with its reticular group lying internal to rather than posterior to the apical group, is shown. The two groups are continuous, and there are several outlying cells near the apical group.

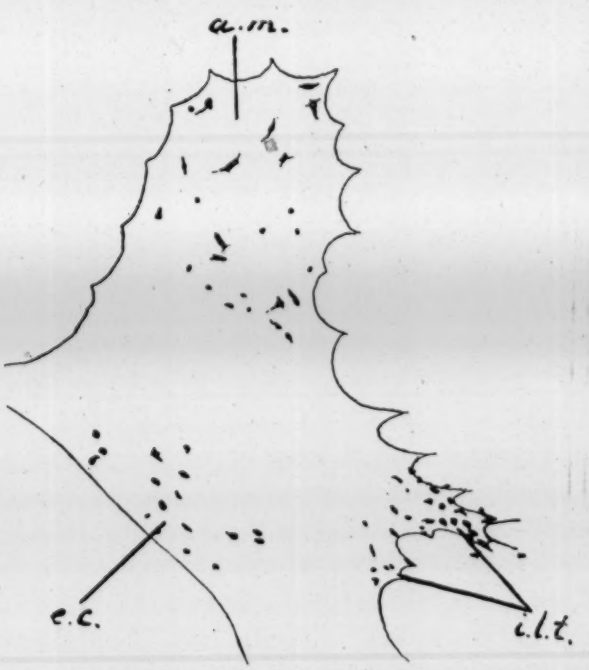

FIG. 16 (D. 9, 413, R.).—The lateral horn shows a sharp apex, directed backwards and outwards, and lying at the level of the posterior half of the column of Clarke. The apical group is distinct and is continuous with the reticular group.

The lateral horns of the two sides continue to present a marked want of symmetry. In the upper part of the segment on both sides the horn presents a blunted or rounded tip, and the apical group lies either at or behind this. On both sides the apex of the lateral horn lies on a plane which passes through the posterior part of Clarke's column (fig. 15, D. 9, 168). On the right side in the lower part a projecting lateral spike appears, and this contains the apical group (fig. 16, D. 9, 413). On the left side the lateral horn has no sharp point, but simply a slightly bulging outline. The cells of the intermedio-lateral tract lie along the outer side of the grey matter, and they extend as far back as the outer side of Clarke's column. The reticular group lies internal to rather than behind the apical group at the upper part of the segment, and on the left side it is simply a backward continuation of the apical group along the outside of the grey matter without any delimitation from it. The cells are not of uniform size in either group, and very large cells from 40 μ to 60 μ are occasionally found scattered through the apical group. The vascularity of the tract, as in D 8, is still very pronounced.

Tenth Dorsal Segment.—The segment was divided into 511 sections. The intermedio-lateral tract contains on the right 10,203 and on the left 8903 cells. The number of cells on the right side thus exceeds that on the left by 1300. This remarkable difference is greater than that found in any other segment. It is one, moreover, which is not attributable to any accidental cause. The cell groups, as represented on the graph, are rounded on the top, and they tend to increase in size in the lower two-thirds of the segment. They are badly marked off from each other, the minima being rarely under 10. The average maximum on the right is about 40, that on the left about 30, the greatest maxima on the left being 46, and on the right 44.

As regards the form of the lateral horn there is asymmetry as great as that in D. 9. The left side has practically no lateral spike, but merely a slight rounded bulging of the grey matter. The apical group is placed either at the most prominent part of the swelling, or, more commonly, a little behind it. On the right side in the upper part there is a slight lateral spike in which the apical group is situated, but throughout the greater part of the segment the lateral horn forms a rounded projection similar to that found in the left side (fig. 17, D. 10, 208). On both sides the apical group may be compact or scattered ; most commonly it is spread out along the edge of the grey matter (fig. 18, D. 10, 225). The reticular group lies behind the apical, and is either continuous with it or separate from it. The boundaries of the whole tract, more especially those of the reticular group, are rather indistinct, especially when the cells are few and scattered, many of these cells being small and little different from the middle-cells and the small cells in the neighbourhood of Clarke's column. As showing the indefiniteness of the boundaries, the enumerations of the different observers presented greater variations in this than in any other segment. The cells, especially in the reticular group, are small. Outlying cells are not common.

Eleventh Dorsal Segment.—This segment was divided into 413 sections. The intermedio-lateral tract on the right side contains 6498 and on the left 6261 cells.

This number is considerably less than the real number, because 24 sections were entirely lost owing to the accident already referred to. In so far as the graph is continuous, the upper end of the segment is similar to that of D. 10. The lower two-thirds show a marked return to a spire-like arrangement and to an increase in the size of the groups, the maxima being generally very high, reaching in section 312 to 55 on the right and in section 302 to 45 on the left side. The groups are more sharply separated than in D. 10, but they cannot be enumerated owing to the loss of sections.

In this segment the reticular group assumes an increasing importance, although it

FIG. 17 (D. 10, 208, R.).—The rounded projection of the lateral horn and its position at a level corresponding to the posterior part of the column of Clarke are shown. The apical and reticular groups form an almost continuous row of cells at the margin of the grey matter. The inner boundary of the group is very indefinite. There are also a few outlying cells.

FIG. 18 (D. 10, 225, L.).—As on the right side, the rounded form of the lateral horn, and its recession to a plane much behind that of the central canal, are shown. The scattered cells and indefinite boundary of both apical and reticular groups of cells which are continuous are also seen.

does not yet exceed the apical group in numbers. Near its lower end as many as 22 cells were counted in individual sections. The group possesses the same character and relative position as in D. 10, but its limits are somewhat more easily determined. There are no complete intervals between the apical groups. The apical cells are arranged somewhat similarly to those in D. 10, with the occasional occurrence of a small separate anterior group. The lateral horn is rounded as in D. 10 in the upper part (fig. 19, D. 181, L.), but at the lower end the spike reappears on the right side (fig. 20, D. 11, 312).

Twelfth Dorsal Segment.—This segment was divided into 405 sections. The intermedio-lateral tract contains 8545 cells on the right side and 7888 on the left. The

graphic representation of the groups shows a return to broad spires somewhat similar to those of D. 3. There are 13 groups on the right and 15 on the left. The greatest number of cells in any one section is 62 (in section 232 on the right side). While the apical group still remains the larger, the reticular has now a maximum number of 35 cells. As in D. 11, the reticular cells are arranged in nests with complete intervals in which there are no cells. These intervals are, however, shorter than in D. 11, so that the reticular group has a relatively greater value in this segment. The apical group is situated partly at the spike-like tip of the lateral horn and along the posterior border,

FIG. 19 (D. 11, 181, L.).—The lateral horn forms merely a slight rounded elevation without any definite pointed tip. The cells of the intermedio-lateral tract are distributed along the margin. The most posterior of them pass as far back as the hinder limit of Clarke's column. Internally they have no definite boundary. The apical and reticular groups are here quite inseparable.

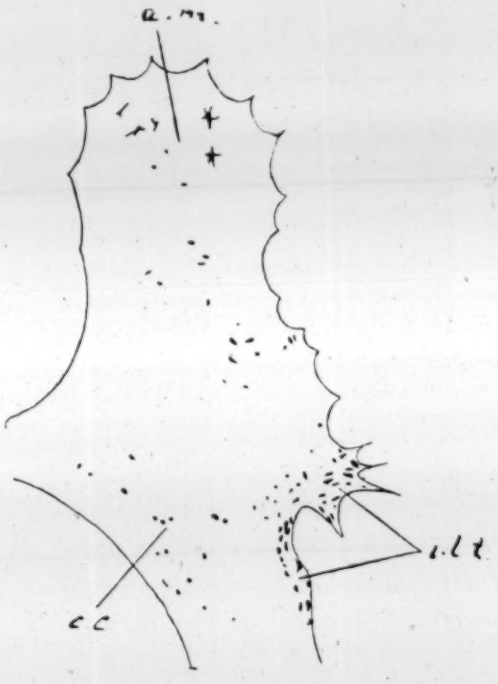

FIG. 20 (D. 11, 312, R.).—The lateral horn has a prominent tip, directed slightly backwards, and lying at a level behind the central canal. Apical and reticular groups are both particularly well-developed. The lateral extends further back than the hinder limit of Clarke's column.

and occasionally has outlying cells amongst the fibres in the neighbourhood of the tip. The reticular group is found either round the re-entering angle and continuous with the apical group, or (fig. 21) it forms a separate group extending somewhat inwards towards the central canal (fig. 22). The two groups show no characteristic difference in the cells, although many of them appear in both groups to be of comparatively large size. The lateral horn is not pointed in the upper half of the left side (fig. 21). On the right and in the lower half of the left it is pointed, and increases in size towards the lower end (fig. 22).

First Lumbar Segment.—This was divided into 352 sections. The intermedio-lateral tract contains 7655 cells on the right side and 7053 on the left. The groups in this segment present in the graph an arrangement into lofty and for the most part slender

spires. There are 19 groups on the right and 18 on the left side. The maximum number of cells in any single section is 78 (section 29 on the left side; fig. 23). The reticular group is increasing in importance and has frequently from 30 to 37 cells. The distribution of the reticular group is along the hinder part of the outer margin of the lateral horn, distinct from or continuous with the apical group, or it may extend inwards as a wedge with its base towards the formatio reticularis. Its cells are fairly large in size, and appear to be somewhat greater than those of the apical group. In the lower fourth of the segment there is interpolated between the apical and the reticular

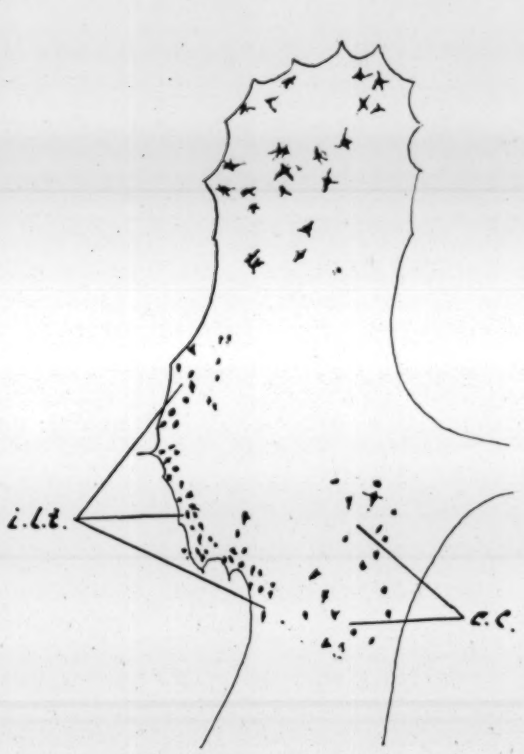

FIG. 21 (D. 12, 172, L.).—The lateral horn is not pointed, but forms a long, full, rounded projection. The intermedio-lateral cells form a continuous group along the whole margin of this swelling from the base of the anterior to that of the posterior horn. Apical and reticular cells are inseparable.

FIG. 22 (D. 12, 287, R.).—This figure shows an instance where the reticular cells are present and the apical series almost entirely wanting.

group a very large third group of cells, containing in some sections 30 cells. This group rapidly reaches a maximum, lasts for some 10 sections, and then rapidly disappears. It is present only on the left side, and the size of the cells is not essentially different from that of the other groups. The reticular group lies on a level with Clarke's column (fig. 24). The apical group is distributed in the spike-like tip of the lateral horn. Occasionally some of its cells pass along the anterior aspect; more frequently they stretch along the posterior border. There are occasional outlying cells in the white matter.

Second Lumbar Segment.—This segment was divided into 208 sections. The intermedio-lateral tract on the right side consists of 1464 cells and on the left of 1123. It somewhat resembled C. 8 in the rapid diminution in the number of its cells. As far as

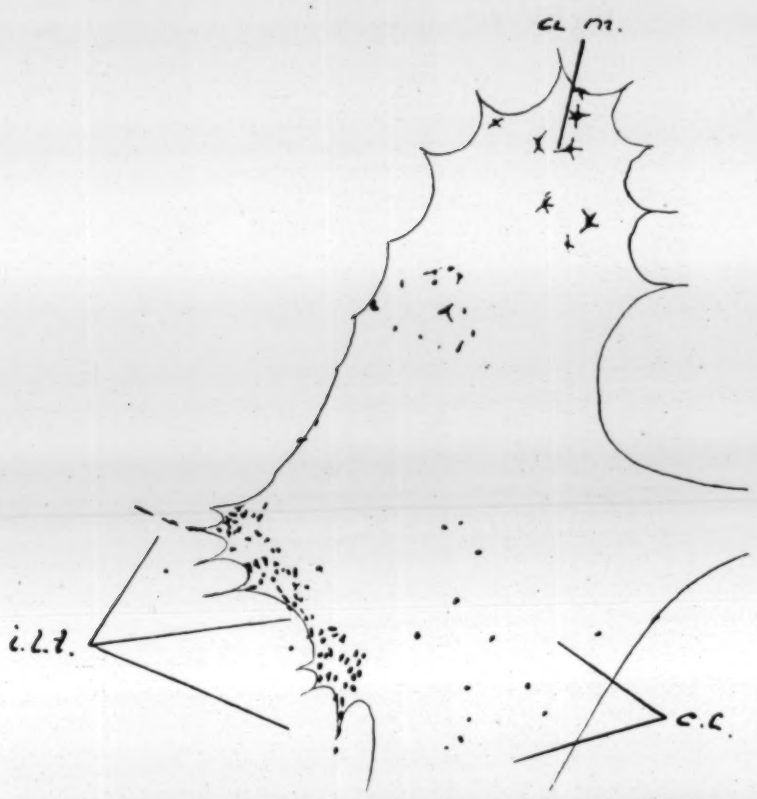

FIG. 23 (L. 1, 29, L.).—The lateral horn forms a pointed projection. The apical and reticular cells are very numerous, and closely aggregated. The two series are continuous.

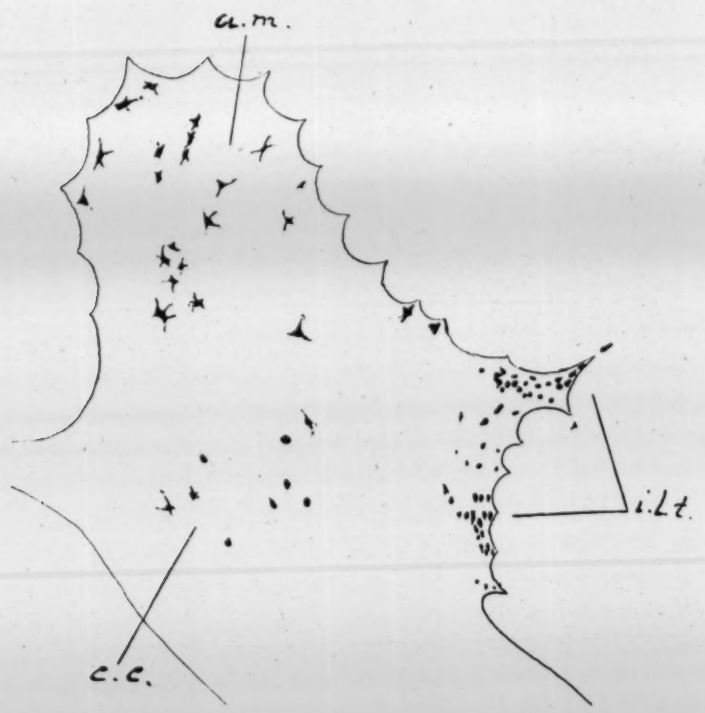

FIG. 24 (L. 1, 187, R.).—The lateral horn is pointed. The apical and reticular cells are numerous but form distinct groups.

section 130 there are small groups of 3 or 4 cells, and beyond this there may be other single cells whose nature it is impossible to determine with certainty. The cells lie at the margin of the grey matter, which is now in front of Clarke's column. There is no apex to the lateral horn, and no distinct definition in the three groups, apical and reticular. There are a few outlying cells below the second lumbar segment.

A few cells are found in the third lumbar segment, which perhaps correspond to the intermedio-lateral tract, but the nature of which cannot be definitely determined.

Conclusions.—From the examination of the graphic representation of the cell-groups and of the microscopic sections, the following conclusions may be drawn as to the distribution of the cells of the intermedio-lateral tract :—

1. The intermedio-lateral tract may be defined as a tract composed of a special series of nerve-cells, situated at the outer margin of that portion of the grey matter which lies between the anterior and posterior cornua. These cells are not necessarily limited to the lateral cornua.

2. Within the spinal cord the tract is found in three regions: (1) in the upper cervical region as low as C. 4; (2) in the lower cervical,. the dorsal and the upper lumbar regions; and (3) in the lower sacral region (below the lower part of the third sacral segment).

3. It is absent in the cervical enlargement from C. 5 to C. 7 inclusive, and in the lumbo-sacral region from L. 3 to the upper part of S. 3 inclusive.

4. In that portion of the tract which is at present under consideration—viz., the second of the above-mentioned divisions—its component cells are found mainly in two positions: (*a*) in the lateral horn proper, or in analogous positions above the level at which the lateral horn is fully constituted; and (*b*) along the margin of that part of the grey matter which is in immediate relationship to the formatio reticularis, and also among the strands of the formatio reticularis itself. For convenience of description and reference these may be distinguished as the *apical cells* and the *reticular cells.*

5. The apical and reticular cell-systems have not a coextensive longitudinal distribution.

6. The apical cells are found between the middle of the upper half of the eighth cervical segment and the lower end of the second lumbar, or the extreme upper part of the third lumbar segment.

7. The reticular cells are first met with in the lower half of the second dorsal segment, and have the same lower limit as the apical series. They are not present in the cervical enlargement.

8. The upper part of the apical cell-series is composed of cells which are either situated in the white matter at some little distance behind the lateral part of the anterior horn, or are applied more or less closely to the grey matter. In all cases the cells are distinct from the large motor cells in their position, size, form, and grouping No transitional forms are anywhere found between the cells of the two series.

9. The lateral horn is not fully constituted above the lower half of the first dorsal segment. This horn is not a transition from the lateral part of the anterior horn, but is a new and independent formation. It is represented in C. 8 and the upper part of D. 1 by the outlying cells of the intermedio-lateral tract.

10. The lateral horns of the two sides may show a want of symmetry in size and form, notably in the lower dorsal and lumbar regions. In the tenth, eleventh, and twelfth dorsal segments the apical cells lie in a plane posterior to the central canal.

11. The middle cells described by WALDEYER do not form any part of the intermedio-lateral tract.

12. The cells of the intermedio-lateral tract vary in size from 12 μ to 60 μ.

13. The apical and reticular cells cannot be distinguished by any essential difference in their form, size, or structure. Large and small cells lying in close juxtaposition may be present in both series in any one section. It has not been found that any group is composed entirely of large or of small cells. Large cells are relatively more numerous towards the lower end of the tract, but they are present alike in the apical and in the reticular series.

14. The number of cells in the intermedio-lateral tract is vastly greater than has hitherto been recognised. The following are the total numbers counted in each segment:—

	Left.	Right.
C. 8	595	429
D. 1	1,867	1,720
D. 2	3,931	3,635
D. 3	7,297	7,471
D. 4	3,623	3,803
D. 5	7,958	7,407
D. 6	8,105	8,030
D. 7	8,739	8,282
D. 8	6,223	5,943
D. 9	9,011	8,987
D. 10	8,903	10,203
D. 11	6,261 +	6,498 +
D. 12	7,888	8,545
L. 1	7,053	6,765
L. 2	1,123	1,464
Total ...	88,577	89,182

These figures are certainly below the total number.

15. The cells of the intermedio-lateral tract do not form a continuous column, but occur throughout the tract in groups or clusters.

16. These groups are not symmetrical on the two sides, although they may present a general resemblance to each other. There appears to be a larger number of cells on the left side in the lower cervical and upper dorsal regions. In the tenth dorsal segment there is a large excess on the right side.

17. These groups or clusters vary in size and form and in their distance from each other.

18. In each segment the cell-groups are arranged in a manner which may be regarded as characteristic of that segment.

19. The number of groups in each segment is somewhat difficult to determine in some cases; generally the number is fairly equal on the two sides.

20. At the upper and lower extremities of the tract there is a tendency for the groups to appear suddenly, to rise rapidly to a maximum, and then quickly to disappear (see graphic chart). Towards the centre of the tract—below the fifth and above the tenth dorsal segments—the groups are less separated from each other. They rise slowly, persist for a considerable length, and diminish slowly. In this region the maximum number of cells attained is never so great as towards the extremities of the tract.

21. There is a remarkable increase in the number of the cells in the third dorsal segment. There is a marked transition in the form of the groups in the middle of the fifth dorsal segment, and another at the middle of the ninth dorsal segment.

22. The intermedio-lateral tract has a vascular supply largely independent of that of the motor cells of the anterior cornu.

23. The segmentation of the tract into groups or clusters of cells is not due to the distribution of blood vessels or of the root fibres, but is probably in some way related to their function.

Although the present communication is intended to be a purely anatomical investigation, its main interest, of course, must be derived from our knowledge of its function, and of the pathological changes which it undergoes in disease.

The researches of GASKELL and LANGLEY as to the outflow of the sympathetic fibres show that the distribution of these coincides in a remarkable manner with the distribution of the cells of the intermedio-lateral tract. It is now certain that the column of CLARKE cannot be the source of the origin of these fibres, and if there is any spinal centre at all it must, by exclusion, be either the "middle cells" of WALDEYER or the intermedio-lateral tract, or both of these.

This communication shows that where there is the greatest outflow of sympathetic fibres there is the greatest number of cells in the intermedio-lateral tract. The cervical sympathetic gets its largest supply of fibres from the portion of the cord included between the eighth cervical segment and the fifth or sixth dorsal segments—segments in which the groups are most rich in cells. Then the outflow of the splanchnics is largest in the lower dorsal region, and here again the number of cells markedly increases and the character of the groups changes. The researches of ANDERSON and HERRING, and of ONUF and COLLINS, seem to point with considerable unanimity to the intermedio-lateral tract as being the source of the sympathetic fibres. It must be admitted, however, that other observers have found conflicting, and sometimes unintelligible,

results of the experiment of section of the nerve, and further researches are obviously needed.

So far as could be ascertained from a mere anatomical examination, no clue as to differentiation of function of the various groups can be obtained from the form of their cells. There were no groups of cells distinguished by a special size or form of cell. There was, it is true, a tendency for the cells in the lower dorsal region to be larger than in the cervical and upper dorsal regions, but these large cells were intermingled with small ones, and nowhere was there any appearance of a group so distinctive as to suggest that its function was essentially different from a neighbouring group.

It is of interest to note that although the total number of cells on the two sides was, as far as could be ascertained, fairly nearly equal, yet that in the cervical and upper dorsal region there was a preponderance in favour of the left side. In the tenth dorsal region, on the other hand, there was a very remarkable preponderance in favour of the right side.

As yet little has been done to connect the pathological changes with disease. The intermedio-lateral tract appears to escape entirely in cases where there is a chronic degeneration of the anterior cornual cells in progressive muscular atrophy and in amyotrophic lateral sclerosis. This may be due to a difference of power of resistance or to a difference of vascular supply. In one case it has been found to be degenerated in connection with erythromelalgia. It may be hoped that future research will succeed in explaining symptoms of visceral and vascular diseases hitherto imperfectly understood.

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DESCRIPTION OF PLATE.

Graphic representation of the arrangement of the cells of the intermedio-lateral tract in the various segments in which it is found.

The numbers below the graph indicate tens of sections.

The numbers placed at the left-hand side of each segment indicate tens of cells.

+ + + in the graph indicate that the number of cells was not ascertained.

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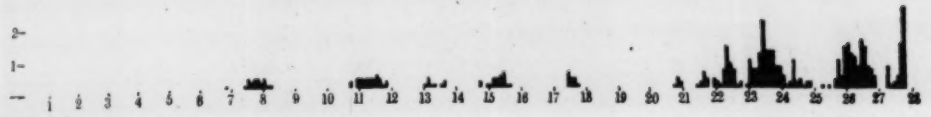

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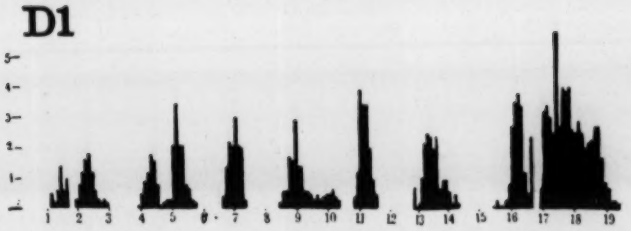

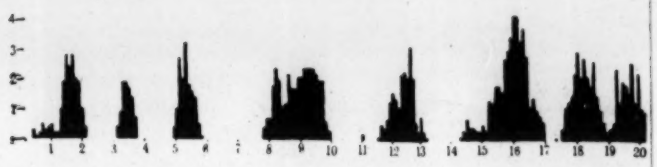

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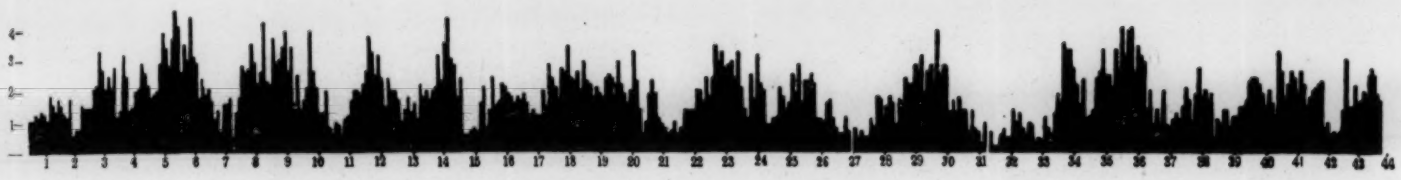

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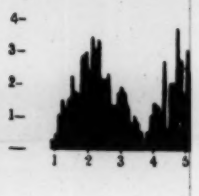

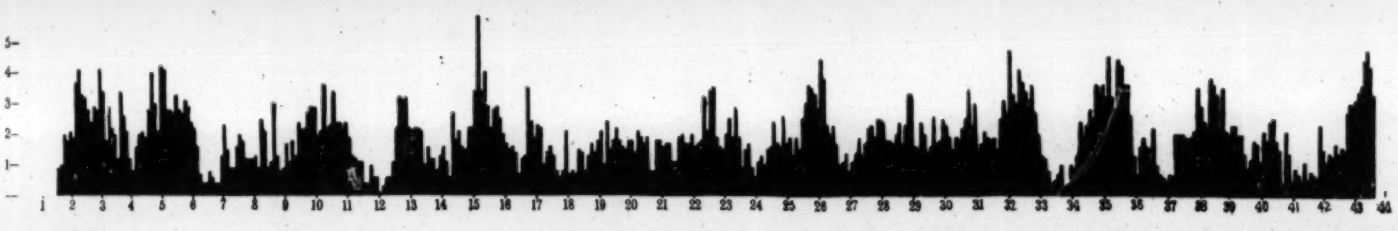

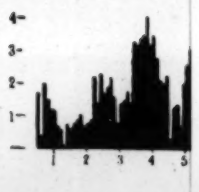

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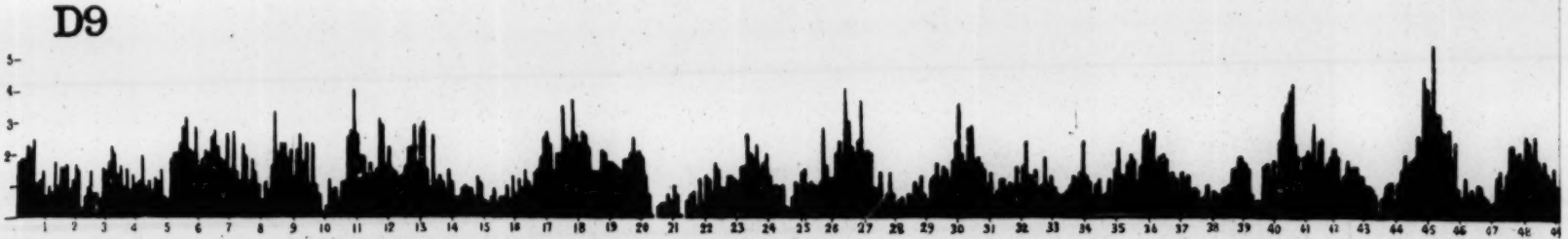

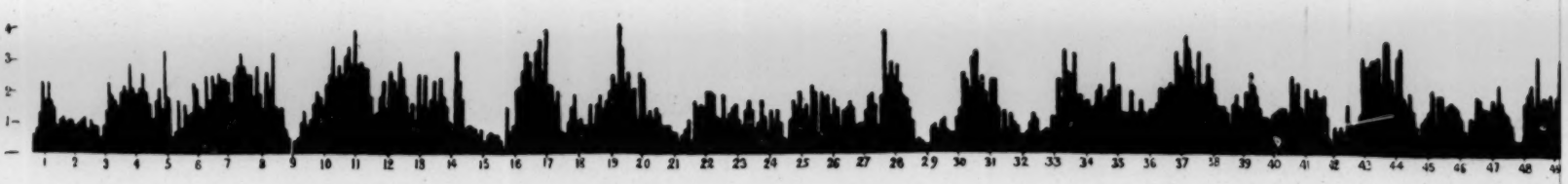

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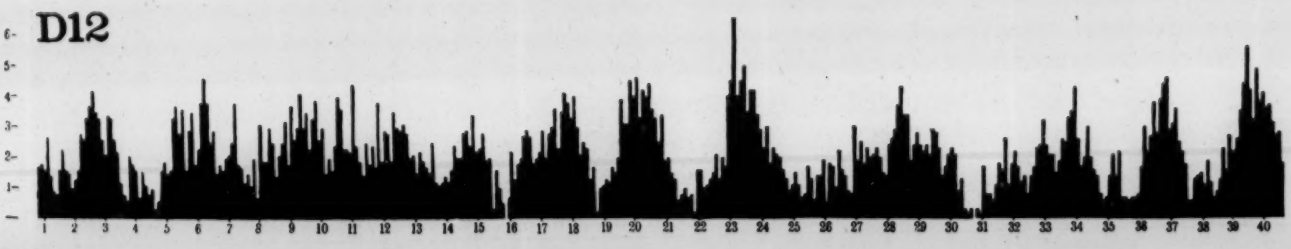

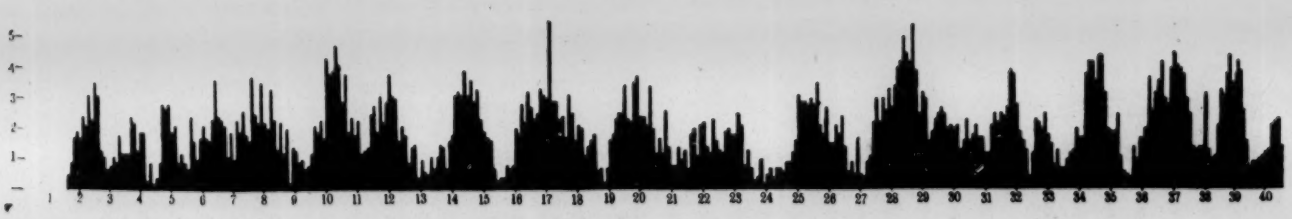

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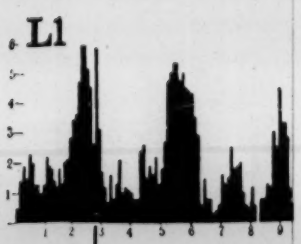

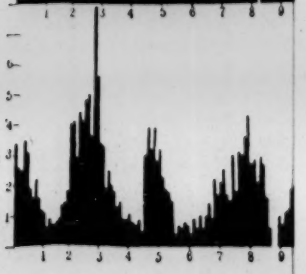

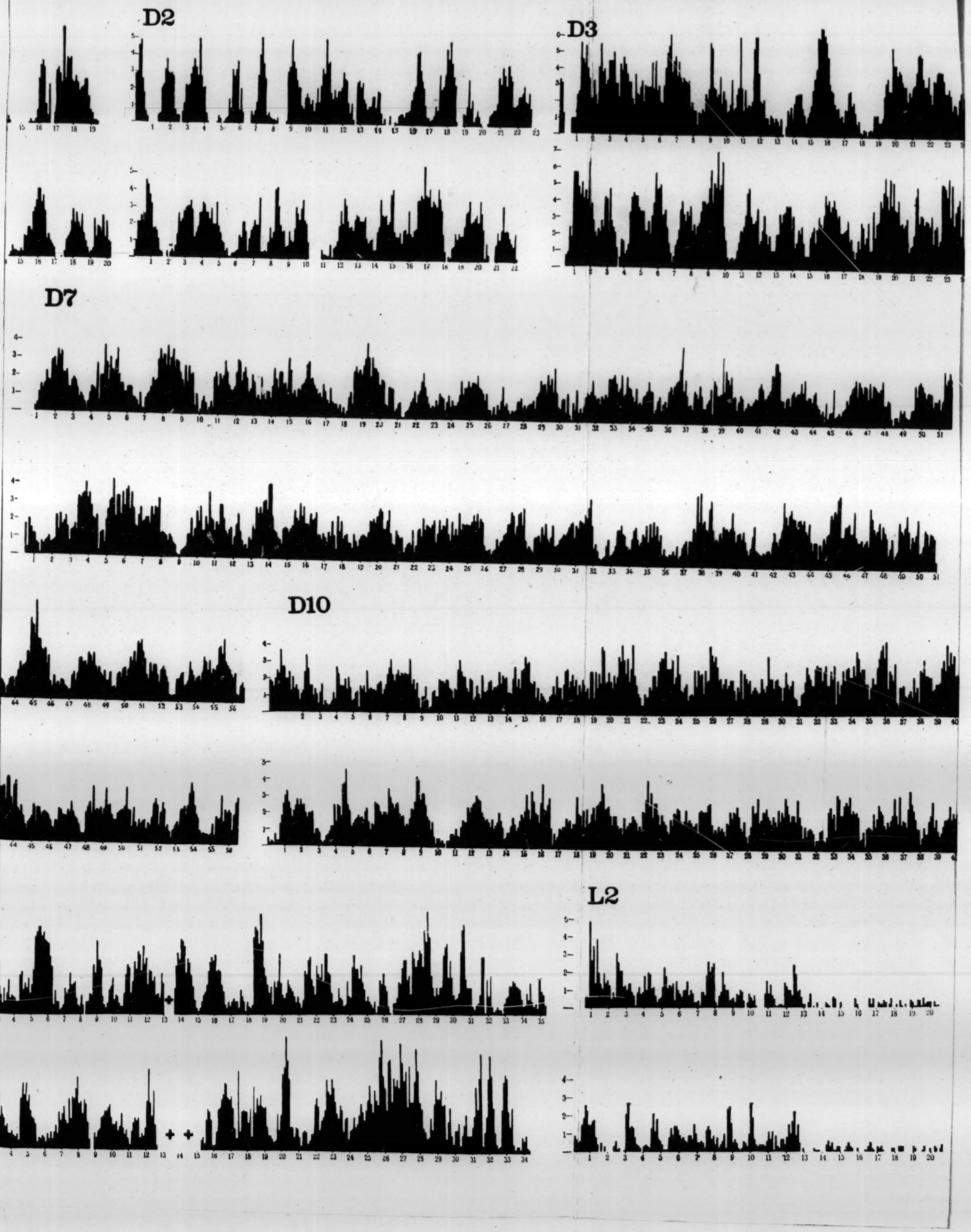
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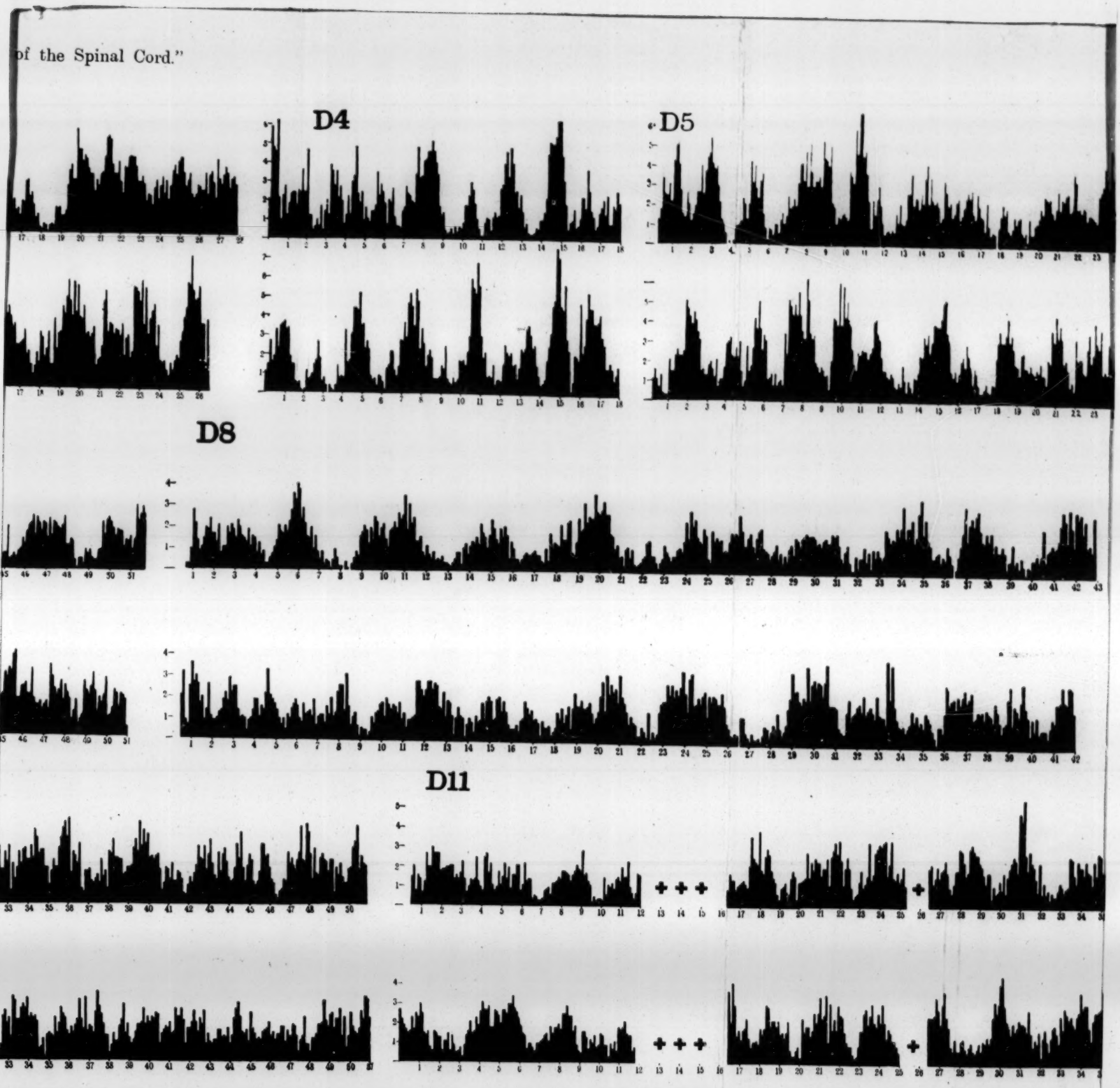
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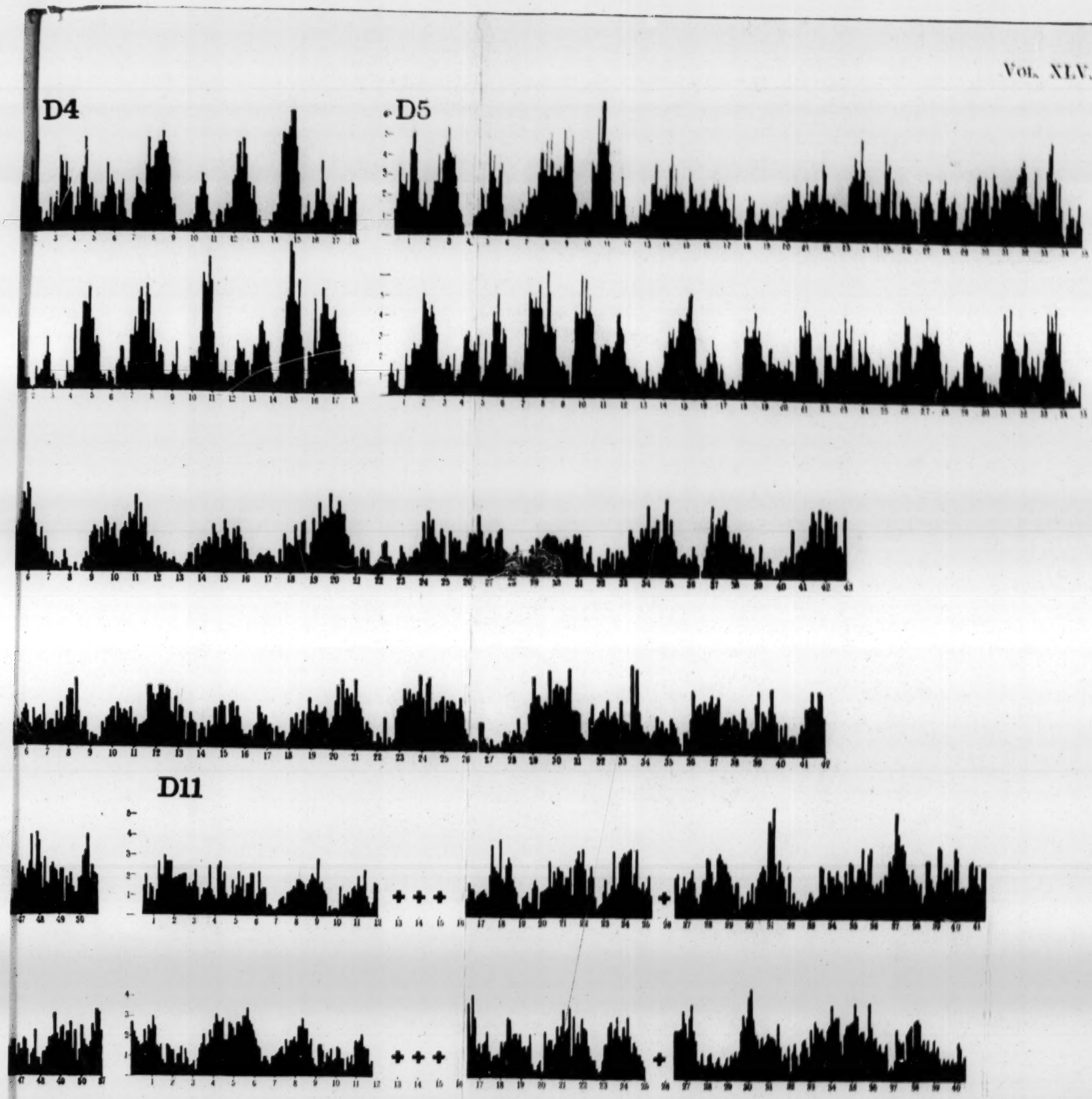
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VI. — The Igneous Geology of the Bathgate and Linlithgow Hills. Part. II. Petrography. By J. D. Falconer, M.A., B.Sc., F.G.S. (With Three Plates.)

(Read March 5, 1906. Issued separately August 13, 1906.)

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1. The Carboniferous Lavas.

Introduction.

The lavas of the Bathgate and Linlithgow Hills occur, as already described,* in a series of zones alternating with sedimentary deposits. So far as their field characters are concerned they may be grouped with convenience into two classes: fine-grained, columnar, basaltic types, usually porphyritic with augite and olivine, rarely with felspar, and coarser-grained, doleritic types, usually much decomposed, not evidently porphyritic or porphyritic with olivine alone. The yellow crusts of the compact lavas are minutely vesicular and pumiceous, while steam-cavities are rare in the interior. The doleritic lavas on the other hand are coarsely vesicular and amygdaloidal above and below, and frequently also throughout. The blue basaltic types are relatively very fresh; the doleritic types are frequently entirely decomposed into a whitish, earthy material, with knots of limonite, calcite, and quartz, similar in many respects to the white trap of the coal-fields. Good examples of this mode of weathering may be found in the Riccarton Burn. The differences in texture are probably to be referred not so much to differences in chemical composition as to the effect of variation in the quantity of water vapour contained in the successive flows. The coarse and open structure of the dolerites has evidently also given freer scope to the action of decomposing influences than the more compact structure of the basalts. Both types are much veined by such secondary minerals as calcite, siderite, limonite, quartz, chalcedony, and various zeolites. Frequently cavities in the veins, steam-holes in the pumiceous crusts, and even vesicles within the solid rocks, are found filled with brown viscous pitch or black lustrous asphalt.

* Falconer, *Trans. Roy. Soc. Edin.*, vol. xli., 1905, p. 359.

Such occurrences undoubtedly indicate that these rocks have been subjected to some slight extent to post-volcanic pneumatolytic action.

Microscopically, the lavas show such a similarity in mineral composition, and such an abundance of intermediate types between the better-marked varieties, that little more than a general summary of their petrological characters can here be attempted.

The Mineralogical Characters of the Lavas.

(*a*) *The Porphyritic Constituents.*

Felspar phenocrysts are rare. Only in the platy basalt overlying the Wardlaw limestone are they found in any abundance, and there the scattered crystals appear to belong mostly to anorthite. Xenocrystic felspars, more or less corroded, are fairly frequent in the more compact lavas, and give extinction-angles for bytownite and anorthite. Occasionally in felspathic types some of the lath-shaped felspars attain a somewhat larger size than the others, but these can hardly be considered porphyritic in the usual sense of the word. Phenocrysts of augite, always clear and undecomposed, are very abundant in the finer-grained types. Sometimes they are sharply idiomorphic, but very generally they are irregularly corroded and penetrated by the groundmass. Polycomatic masses of augite are frequent, and these may have arisen in some cases by the aggregation of imperfect crystals, and in others by the fracturing during eruption of original augite phenocrysts. The colour is a pale brown or violet, frequently deepening in tint on the margins, and rarely giving place to green in the interior. A multiple zonary arrangement of tints is occasionally observed. Inclusions of magnetite and groundmass are very abundant, and sometimes sharply confined to the interiors of the crystals. The augites are frequently sensibly pleochroic, and simply or repeatedly twinned on the orthopinacoid. Aggregations of small augite crystals, resembling those formed during the resorption of quartz in basic rocks, are occasionally observed, and probably represent original xenocrystic quartz. The worn remains of the quartz grain may sometimes be observed in the centre of the aggregate. Olivine in phenocrysts is abundant throughout. Long rectangular crystals and pyramidal forms are equally common, always more or less corroded and replaced by masses of serpentine, magnetite, chalcedony, or calcite. The serpentine may be stained red or brown, marginally or completely. Pseudomorphs of pleochroic iddingsite are fairly common. Nodular masses of various minerals, sometimes as large as a marble and perhaps to some extent xenocrystic, may be picked out of many of the lavas. These include granular aggregates of rounded crystals of anorthite and schillerised augite as well as intergrowths of augite and anorthite, and augite and olivine, usually much corroded by the basaltic magma.

(*b*) *The Groundmass.*

The groundmass is composed of small crystals of felspar, augite, magnetite, and more rarely olivine, and a varying quantity of undifferentiated glassy base. The felspars

are lath-shaped, clear, and undecomposed, with few inclusions other than portions of the glassy base, from which the terminations of the crystals and the basal planes are frequently imperfectly marked off. Twinning both on the albite and the carlsbad laws is very general, and from the extinction-angles there appears to be present a mixture of plagioclases of the labradorite-andesine series. In the doleritic types a simply or multiply twinned felspar in irregular plates seems to act to some extent as matrix. It has invariably a lower refractive index than the lath-shaped felspars which it encloses, and probably belongs to oligoclase. The augite occurs either in tiny idiomorphic crystals or in small rounded granules, usually aggregated into little heaps. More rarely in the dolerites it builds small ophitic plates between the felspars. The magnetite occurs in idiomorphic cubes or open networks or feathery skeletal crystals.

The glassy base is typically brown and microlitic, and when abundant imparts a dark lustrous sheen to the hand specimen. In some cases it seems to be undergoing a local clarification, with occasional development of anomalous refractive effects. The discrimination of such material from analcite is frequently difficult, but in this and similar cases it is convenient to adopt Evans' criterion, that in the absence of any trace of crystalline structure the material should be considered hyaline.* In these rocks the doubtful material, so far as observed, never shows a crystalline structure, while the true analcite is so obviously secondary that it is very probable that no primary analcite ever existed in them. The production of secondary analcite, which is sometimes very abundant in the coarser-grained types, begins with the replacement of the felspathic matrix, or of the intersertal glassy material by a yellowish granular isotropic substance, which only later assumes the properties of analcite. The change can frequently be observed advancing from its point of origin into the surrounding rock, the outlines of the original lath-shaped felspars being occasionally recognisable within the brown isotropic pseudomorph. (See Pl. I. fig. 1.) It is highly probable that pneumatolytic action as well as atmospheric weathering has been concerned in the production of the change.

Structure, Classification, and Chemical Composition.

The variations in structure are largely dependent upon the relative abundance of felspar, augite, and glassy base in the groundmass, and as this affords also a basis for classification, it is unnecessary to describe the structural modifications apart from the general composition of the various members of the series. Five well-marked and recurrent types are readily distinguished, each connected with the others by imperceptible gradations, the members of any one group varying slightly in texture amongst themselves.

1. Coarse-grained doleritic rocks, usually amygdaloidal and much decomposed, non-porphyritic, or porphyritic with olivine alone, more rarely with augite. The felspar of the groundmass is more abundant than the augite which occurs in granules, granulitic

* Evans, *Quart. Journ. Geol. Soc.*, vol. 57, 1901, p. 49 ; see also Flett, *Trans. Roy. Soc. Edin.*, vol. xxxix , 1900, p. 865.

masses, small ophitic plates, or tiny idiomorphic crystals between the felspars. Residual glassy base may be present in small quantity as intersertal material, and sometimes portions of the matrix are felspathic and replaced by analcite as described above. The quarries at North and South Mains furnish good examples of this type. Somewhat finer-grained varieties with a similar structure are common in the Bo'ness hills. (See Pl. I. figs. 1, 2.)

2. Fine-grained basaltic rocks, porphyritic with olivine and augite. The felspar of the groundmass is more abundant than the augite, and owing to a slight increase in the amount of glassy base assumes very generally a fluidal or parallel arrangement. The small augites are idiomorphic or granulitised, and more or less aggregated between the felspars. The lava of Duncanseat quarry may be taken as a typical example.* (See Pl. I. fig. 3.)

3. Fine-grained and compact basaltic rocks, porphyritic with olivine and augite. The augite and felspar of the groundmass are in approximately equal quantity, and homogeneously mixed with a little glassy base. Fluxion structures are typically absent. The basalt above the limestone at the Knock shows this structure fairly well. (See Pl. I. fig. 4.)

4. Compact basaltic rocks, porphyritic with olivine and augite. The augite of the groundmass is much more abundant than the felspar, and usually granulitised. The lath-shaped felspars form an open network, the meshes of which are filled with heaps of augite granules. A small quantity of glassy base is usually present. The basalt of West Kirkton quarry is a typical example.† (See Pl. I. fig. 5.)

5. Compact lustrous basalts, porphyritic with olivine and augite. Brown glassy base is abundant, and the felspar of the groundmass is usually reduced in amount. When the felspar is almost wanting, the rocks assume a limburgitic character. Good examples of this type may be found in the quarries at Tartraven and Kipps. (See Pl. I. fig. 6.)

The silica has been estimated in one example of each type with the following results :—

	Type I.	Type II.	Type III.	Type IV.	Type V.
SiO_2	45·65	44·41	41·20	41·53	41·39

I. Fine-grained dolerite, Bell's Knowe, Bo'ness.
II. Basalt, north of Tartraven Castle.
III. Basalt, 300 yards south of Kipps Hill.
IV. Basalt, old quarry, 300 yards S.S.E. of Hilderston Hills.
V. Basalt, western slope of Cockleroy.

Types I. and II., the more felspathic varieties, are, as was to be expected, somewhat more acid than the others. Types III., IV., and V. have practically the same amount of silica. The differences between them in mineral composition must therefore be due largely to variations in the rate of consolidation. Only in the Riccarton Hills is it

* A. Geikie, *Trans. Roy. Soc. Edin.*, vol. xxix., 1880, Pl. XI. fig. 4. † *Ibid.*, Pl. XI. fig. 5.

possible to establish a sequence, the lower lavas there being doleritic and more acid, the higher basaltic and more basic. Elsewhere, doleritic and basaltic flows are irregularly intermingled.*

2. The Contemporaneous Intrusions.

These are the product of the same period of igneous activity as the lavas. They include both doleritic and basaltic types, but present few features of general interest. The rock of Mochrie's Craig and Peace Knowe is remarkably decomposed with production of much kaolin, calcite, serpentine, and analcite. It varies much in texture from point to point, and in places assumes a spotted character from local aggregations of ferromagnesians.

3. The Later Intrusions.

Introduction.

The diabases of later age occur (1) in a series of E.-W. dykes of no great breadth crossing almost at right angles the outcrops of the various lava zones; and (2) in a series of rudely columnar intrusions of dyke-like and laccolitic habit, elongated in a N.-S. direction, and occasionally of considerable thickness. A genetic relationship without doubt exists between the two. Their petrographical similarity, first pointed out in a classic paper by Sir A. Geikie,† has been fully established on more detailed study, and it is impossible to resist the conclusion that the dykes and sills are the products of the same distinct period of igneous activity. Their age alone still remains rather doubtful. Sir A. Geikie, on the assumption that the E.-W. dykes were of Tertiary age, was of opinion that the sills also should be referred to that period. Of late years, however, doubt has arisen as to the Tertiary age of the dykes, while, on the other hand, sills in Eastern Fife of a similar character to those in the Linlithgow area have been referred almost certainly to late Palæozoic times. Hence it is possible to consider of Palæozoic age all the material possessing the same peculiar structure found in the basin of the Forth, whether it occurs in dykes or in sills. In the Bathgate Hills, however, no positive evidence has been found apart from the fact that some of the smaller faults, themselves probably late Palæozoic, displace the long sinuous intrusion of the Raven Craig.

The central portions of the dykes and sills are very coarse-grained, and to the eye evidently composed of a granular mixture of a grey or pink felspathic and a dark green ferromagnesian constituent with black lustrous iron-ore and a considerable amount of pyrites. In the smaller intrusions the rock is homogeneous throughout, but in the larger dykes, and especially in the sills, a local differentiation is very common into a darker coloured variety in which augite is more abundant than felspar, and a lighter coloured variety in which felspar evidently predominates.‡ In the latter, the ferromagnesian

* The Tuffs accompanying the lavas have not been investigated in any detail. For a short description of these, see Geikie, *Trans. Roy. Soc. Edin.*, vol. xxix., 1880.

† A. Geikie, *Trans. Roy. Soc. Edin.*, vol. xxxv., 1896, p. 21.

‡ *Cf.* "The Geology of Eastern Fife," *Geol. Sur. Mem.*, 1902, p. 190.

constituent frequently appears in beautiful branching forms, the fibres being of considerable length and variously curved, while the felspars are much elongated, striated, or unstriated, and more rarely slightly bent. The lighter and darker coloured varieties are frequently associated irregularly in the same specimen, and sometimes the association is so intimate as to give rise to a spotted appearance in the rock. Variations in texture are sometimes to be observed, and occasionally very coarse-grained patches are found, frequently exhibiting a central cavity which may be filled with calcite, chlorite, or quartz, or with water, clear mineral oil, brown solid paraffines, or black viscous pitch. Such cavernous knots are met with from time to time in the Linlithgow quarries, and are to all intents and purposes druses, probably originating through concentration of steam at various points within the cooling mass, and a consequent slower crystallisation in the surrounding magma. The rocks weather with a brown crust, and crumble into a coarse felspathic sand.

The dykes and sills pass marginally into fine-grained blue aphanites, which, at a distance of 2–6 ft. from the junction, may develop a spotted appearance, investigated below. The spots are dark green, and sometimes weather out as knots on the exposed surface, being more resistant than the surrounding rock. Nearer the junction vacuoles and amygdules are abundant, the latter sometimes elongated at right angles to the plane of contact. At the junction the rock assumes a fine-grained basaltic character, usually porphyritic with scattered felspars, ferromagnesians, and pyrites. Glassy modifications have not been observed.

The larger sills, as exposed in the Kettlestoun and Carribber quarries, are crossed by irregular contemporaneous veins of two varieties: (1) blue and fine-grained, (2) pink and coarse or fine in grain; known locally as "blue-band" and "iron-band" respectively. Sometimes fragments of the coarser rock are enclosed in the veins as if some slight brecciation had occurred in places. The veins, however, are never sharply marked off by chilled edges from the surrounding rock, their material passing, as a rule, quite gradually into the intersertal material of the host.

Contact metamorphism is rarely seen, probably from the absence of exposures. Here and there, shales and sandstones are baked and hardened, but with no obvious new formation of minerals other than pyrites. In Carribber Glen, a calcareous rock, interbedded with ash, has been completely metamorphosed into a blue crystalline granular limestone, with abundant production of colourless transparent garnets in a matrix of calcite, chlorite, and chalcedony.

Mineralogical Characters of the Diabases.

In the felspars, a columnar habit is general throughout, the crystals being elongated on the "a" axis with equal development of 001 and 010. The length varies considerably, the maximum being obtained in the lighter coloured portions of the larger sills. In section the brachypinacoids are usually sharply defined; frequently, however, the terminations, and occasionally also the basal planes, are imperfectly marked off from the

surrounding mesostasis. More rarely the intersertal material appears to have exerted a corrosive action upon the felspars. Fresh crystals have the cleavages well marked, and possess inclusions of apatite and iron-ores. Decomposition gives rise to abundant micaceous material mixed with kaolin and calcite, the process in most cases beginning in the interior. Between crossed nicols the crystals are generally striated, showing, however, a comparatively small number of albite, and less frequently a few pericline lamellæ. Carlsbad twinning is very generally associated with albite twinning. The great majority of the crystals are imperfectly zoned, giving a progressive or continuous extinction from centre to margin. Untwinned brachypinacoidal sections give angles for the different zones varying from $-30°$ to $+5°$, indicating that the crystals change gradually in composition from labradorite to oligoclase, the largest part of the crystal as a rule belonging to labradorite. This is confirmed by observations on suitable macropinacoidal sections.

In some of the grey or red felspathic varieties, however, the crystals of felspar are largely untwinned, or only simply twinned, and rarely zoned. In many long columnar crystals the basal cleavage, probably accentuated by secondary changes, has produced a herring-bone structure, similar to that found in augite, and this, coupled with the simple twinning, has led many observers to refer these crystals to orthoclase.* Neither of these features, however, is confined to monoclinic felspars, and where no more exact determinations have been made such statements as to the presence of orthoclase in diabases should be received with great reservation. Stecher explained the herring-bone structure of the felspars as a micropegmatite of plagioclase and quartz.† Such formations undoubtedly do occur, but usually as intersertal products or corrosion-effects, while columnar felspars with herring-bone structure are, as a rule, free from quartz. So far, the only authenticated occurrence of orthoclase in these rocks is that recorded by Dr Flett from Eastern Fife, where the true nature of the felspar was determined by observations on cleavage flakes.‡ Orthoclase in columnar crystals has not yet, however, been found in any of the diabases of the Bathgate Hills. Determinations of the refractive index of many untwinned and simply twinned felspars, by means of mixtures of cassia and olive oils of known refractive indices, have shown that such crystals really belong to acid plagioclase. The content in potash which the analyses reveal, must, therefore, be referred to the mesostasis where orthoclase may occur in tiny crystals or in micropegmatitic intergrowth with quartz.

Pyroxenes are the only ferromagnesian minerals found in the fresh and unattacked rock, and the predominating pyroxene is a pale brown augite which varies much in habit. True ophitic augite in large allotriomorphic plates or polysomatic masses enclosing crystals of felspar is comparatively rare, and occurs locally in the marginal portions of the sills. (See Pl. II. fig. 1.) Throughout the dykes, however, and also on the margins of the sills, a hypidiomorphic granular augite with a tendency to ophitic

* A. Geikie, *Trans. Roy. Soc. Edin.*, vol. xxix., 1880. † Stecher, *Tsch. Min. u. Petr. Mitth.*, vol. ix., 1887.
‡ "The Geology of Eastern Fife," *Geol. Sur. Mem.*, 1902, p. 391.

structure is commonest. Where enclosed in felspar or in mesostasis the augite shows idiomorphic outlines, but where it encloses felspar it is allotriomorphic and ophitic. Frequently the same crystal may be in part idiomorphic and in part ophitic, the peculiar habit being due to the more or less simultaneous crystallisation of felspar and augite.* In the central portions of the sills the augite assumes a long columnar habit, rarely idiomorphic in the prism zone. (See Pl. II. fig. 2.) Smaller felspars are occasionally enclosed in an ophitic manner on the margins, but as a rule the felspathic material has crystallised later and moulded the augite. The later quartz has also sometimes exerted a corrosive action upon the augite where not protected by being enclosed in felspar. It is thus very probable that the general absence of definite outlines where such were to be expected is due to the extensive corrosion which the augite has suffered after crystallisation. These columnar crystals have also frequently suffered a mechanical deformation,† being bent into various curving forms, and often broken transversely when the limit of elasticity has been passed. (See Pl. II. fig. 3.) Almost any section from Carribber quarry will show this peculiar structure. The long columnar felspars, however, so rarely show any trace of bending that the phenomenon must be ascribed to some movement within the igneous mass soon after the augite had crystallised out. Most probably the central framework of columnar augites, which may be supposed to have been formed within the igneous magma, was, on reduction of the volume of the mass, unable to withstand the pressure of the overlying rocks, and in consequence collapsed, the individual augites being in many cases bent, shattered, and broken. In the lighter coloured portions of the larger sills the augite frequently assumes, macroscopically, a long curving and branched prismatic form with notable idiomorphism, the various branches from the same stem being arranged in a fan-like manner in the same plane. Similar occurrences, though microscopic, are sometimes found in the diabase aphanites and in their ocelli. (See Pl. III. fig. 1.) It is difficult to account for this peculiar habit. It certainly cannot be considered the result of resistance to growth in a viscous medium (as feathery crystals usually are), for, apart from the notable idiomorphism of the fibres, the augite, which is always of the purplish brown type, was here one of the first minerals to crystallise, and is usually found enclosed in the columnar felspars. Most probably the peculiar habit is due to the poverty of certain portions of the magma in calcium and magnesium.

The shape of this idiomorphic augite is noteworthy. As a rule the pinacoids are greatly developed at the expense of the prism faces; consequently transverse sections, both of the stout idiomorphic prisms and of the finer branching crystals, assume outlines which are much nearer those of rhombic pyroxene than of ordinary basaltic augite. This introduces a certain element of uncertainty into the recognition of serpentinous and chloritic pseudomorphs of these minerals.

The augite crystals, both ophitic and columnar, are frequently twinned on the ortho-

* *Cf.* "Sub-ophitic" structure, WATTS in GEIKIE'S *Ancient Volcanoes of Great Britain*, vol. i. p. 147.

† ROSENBUSCH, *Mikro. Phys.*, vol. ii. p. 130.

pinacoid. Inclusions of apatite, iron-ores, and devitrified material are usually abundant. The decomposition is interesting and important, and varies in character according as the process begins in the interior or on the exterior of the crystals. In the former case, a grey or pale brown granular material first forms in the centre of the crystal, and renders the transparent augite quite opaque. (See Pl. II. fig. 1.) This is usually accompanied by the development or accentuation of the basal lamellar cleavage, which is not always recognisable in fresh augite,* and which, coupled with the simple twinning gives rise to the familiar herring-bone structure. Further decomposition results in the development of viriditic material, either as an irregular felted mass of minute scales, fibres, and granules in the interior of the crystal, or as a regular platy or fibrous aggregate, the fibres being parallel to the basal cleavage and more or less transverse to the vertical axis of the crystal. The process may continue until the whole of the augite has disappeared, its place being taken by a pseudomorph of irregular or of regular structure. The material with a regular arrangement is sometimes a fibrous uralite, with a slightly oblique extinction. At other times it assumes quite a micaceous character, with a distinct cleavage, a marked pleochroism from green to yellowish brown, and a straight extinction. Its bi-refringence, however, is much nearer that of chlorite than of mica, and it ought probably to be referred to the chlorite group. A similar mineral has been described from diabases by various writers, and it is probable that this is also the so-called "delessite" of the earlier investigators.

Out of the green irregular felted material recognisable minerals frequently develop. Ragged fan-like aggregates of the above "delessite" are found associated with scaly, starry, or spherulitic masses of ordinary prochlorite, nests of minute green needles of actinolite, granules of epidote and tiny crystals of rutile. The production of these minerals is usually accompanied by the deposition of much calcite and quartz, probably largely derived from the augite itself. The quartz occasionally occurs in dihexahedral forms, but its secondary origin is usually recognisable from the nature of its inclusions or the associated minerals. Occasionally in the calcite is found embedded another green micaceous mineral, sharply idiomorphic, with rectangular vertical, and hexagonal transverse sections. The pleochroism, except in basal sections, is very strong, from deep green to golden yellow. The cleavage is basal and perfect, and in basal sections partings parallel to the sides of the crystal, and meeting at 60°, are frequently to be observed. The bi-refringence is high, giving sometimes the brilliant green of the third order. The greatest absorption is parallel to the cleavage, and basal sections yield a negative uniaxial interference figure. The mineral is probably a slightly chloritised secondary mica.†

When the decomposition of the augite begins on the exterior of the crystals, the original colour changes to a greenish brown, and the mineral becomes pleochroic and gradually assumes the cleavage and properties of brown common hornblende. The change gradually works inwards, the line of junction in the interior being highly

* See HARKER, *Quart. Journ. Geol. Soc.*, vol. l., 1894, p. 317. † FLETT, *Geol. Sur. Mem.*, sheet 55, p. 128.

irregular. Usually a narrow band of augite, flecked and spotted with brown hornblende, intervenes between the compact augite and the compact hornblende. The smaller crystals may in this way be completely replaced by clove-brown hornblende, but frequently the centre of such a secondary hornblende is occupied by a mass of chloritic material representing the portion of the augite which succumbed to the other process of decomposition already described. Frequently both processes may be observed in the same crystal, a ring of undecomposed augite marking off the chloritic core from the hornblendic margin. Plates of brown mica, also secondary, are occasionally found associated with the hornblende, and both minerals, although more stable than the augite, themselves apparently undergo a further decomposition. In the hornblende, the brown changes to a green colour, which appears first in isolated spots and then spreads over the whole crystal. At the same time a closer cleavage is developed, and the compact hornblende becomes a mass of pale green or colourless fibrous actinolite. This green, reedy hornblende, and also the biotite, change finally into scaly chlorite or into the lamellar "delessite" described above.

Although for descriptive purposes the hornblende has so far been considered secondary, it ought not to be forgotten that much could be said in favour of its being considered in primary intergrowth with the augite. The question has been repeatedly discussed in petrological publications, and it would seem that in most cases the same evidence can be read both ways. Consequently one cannot but accept ROSENBUSCH'S conclusion that "definite discrimination between the two is only possible when the hornblende occurs in its own form or in that of augite: if the external form fails, the discrimination must always remain uncertain."* In these diabases I have been unable as yet to find any definite primary outlines in the hornblende, and until these are found it is most convenient, especially in view of the occasional occurrence of hornblende with the outlines of augite, to consider the whole of secondary origin.

Traces of the hornblendic decomposition may be found everywhere in the augite of the dykes and sills, but it is in the columnar augites of the larger sills that this interesting change reaches its greatest development. Curiously enough, it has progressed farthest in those portions of the rocks which contain the largest quantity of mesostasis, and even there it is to be noted that those portions of the augite crystals which abut against the mesostasis are more completely amphibolised than those which are enclosed in or surrounded by felspar. The plagioclase seems in some way to have preserved the augite from decomposition or at least hindered the process.†

In various portions of the dykes and sills a rhombic pyroxene is an abundant accessory. Its distribution, however, is exceedingly sporadic, and in any one sample its presence can never be guaranteed. It appears to be most commonly associated with the ophitic or sub-ophitic augite, and builds either large irregular plates or short stout columns idiomorphic in the prism zone. As a rule, it has crystallised out before the

* *Mikroskopische Physiographie*, etc., vol. ii. p. 1108.
† *Cf.* HOLLAND, *Quart. Journ. Geol. Soc.*, vol. liii., 1897, p. 405.

augite, and is occasionally found aggregated into little clumps. When fresh it is pale brown in colour, and faintly pleochroic to a very pale green, and otherwise closely resembling the rhombic pyroxene in the Ratho diabase.* The mineral appears to be near bronzite, the pleochroism not being sufficiently marked for hypersthene. Usually the bronzite is more weathered than the augite with which it is associated, and is partially or wholly replaced by a fibrous bastite. (See Pl. II. fig. 6.) In many sections may be observed short rectangular or eight-sided pseudomorphs in serpentinous and chloritic minerals which may be after bronzite, but which, in view of the peculiar habit of the augite described above, should probably be more properly referred to monoclinic pyroxene. In many dykes, however, and also in the sills, there occur pseudomorphs of a ferromagnesian mineral in a micaceous substance resembling iddingsite. These occur in long rectangular and eight-sided sections, which have much more the habit of rhombic pyroxene than of olivine. Frequently undecomposed remains of pyroxene are found within the pseudomorph, and these sometimes extinguish straight and sometimes oblique. Further, true augite is occasionally found with a border of the same compact, intensely pleochroic material. It is probable that these secondary formations are pseudomorphs, both after bronzite and after ordinary augite rich in magnesia. It is interesting to note, also, that wherever monoclinic augite is found decomposing in this way, the portions still undecomposed have a faint but distinct pleochroism similar to that of the bronzite.

Olivine, completely serpentinised, is found everywhere on the margins of the dykes and sills, but only very rarely in the interiors of the smaller dykes, and not at all in the central portions of the sills. Its place appears to be taken in the coarser rocks by rhombic pyroxene of somewhat similar composition. Where both bronzite and olivine are wanting, their Mg-content is probably included partly in the augite and partly in the ilmenite.

Apatite is very abundant, and builds long slender needles, frequently continuous through several crystals of felspar, augite, and quartz. One or more axial canals, filled with glassy material in the form of negative crystals, are fairly common. Ilmenite or titaniferous magnetite is everywhere abundant, and occurs in the form of large, compact, or thin detached and parallel plates, or in open porous crystals. In the central portions of the sills it frequently builds elongated skeletal forms, round which the columnar augites have grown in such a way as to simulate a pegmatitic intergrowth. Late crystallisations of iron-oxide like that described by Monckton † have not been recognised with any certainty. Pyrites is common throughout, and occurs usually in the form of irregular masses and porous cubes, and frequently in a granular condition in the cracks and cleavages of felspar and augite, and has evidently been one of the latest minerals to crystallise.‡ (See Pl. II. fig. 1.)

* Teall, *British Petrography*, 1880, p. 163.
† Monckton, "The Stirling Dolerite," *Quart. Journ. Geol. Soc.*, vol. li. p. 48.
‡ *Cf.* Vogt, *Zeitschrift für praktische Geologie*, April 1893, fig. 27.

The Intersertal Material or Mesostasis.

Throughout the dykes and the marginal portions of the sills, the intersertal material, which, though always crystalline, may be spoken of generally as mesostasis, is found in comparatively small quantity. Locally it is aggregated with felspar into knots which are readily recognised by their imparting a red or grey spotted appearance to the rock. The greatest development of mesostasis, however, is found in the central portions of the larger sills, and there perhaps most abundantly in the pale-coloured felspathic modifications. There also its nature can be most readily investigated. Under the microscope the angular spaces between the columnar felspars and augites are partially or wholly filled with a micropegmatitic growth, in which the proportions of quartz and felspar may apparently vary considerably within a few millimetres. (See Pl. II. figs. 2, 4, 5.) The amount of quartz increases, as a rule, towards the centres of the intersertal spaces, and angular or irregular portions of the same mineral are frequently found embedded in the linear micropegmatite. These may be either earlier crystallisations or later corrosion effects. (See Pl. II. fig. 5.) As a rule, a band of linear micropegmatite lines, as it were, the walls of the intersertal cavity, especially where these are formed of plagioclase, with which the later felspar is frequently in optical continuity. Where an augite forms a portion of the wall it is only where there has been an abundant supply of material that it also is provided with a micropegmatitic fringe. Usually there is a gap in the continuity of the lining opposite to the augite. The interiors of the intersertal spaces are very generally filled with an allotriomorphic micropegmatitic growth from various centres, or more rarely by a mass of cryptocrystalline material, or by a trachytic aggregate of small felspar crystals with a little interstitial quartz. Occasionally, also, a coarse-grained micropegmatite or a granular aggregate of quartz and felspar crystals, or a mass of felspar or of quartz alone may occupy the centre. Small idiomorphic felspar crystals may sometimes be seen projecting from the walls into such a central mass of quartz. Micromiarolitic cavities are also occasionally observed with the walls lined with tiny idiomorphic crystals of quartz, and the interior loosely filled with secondary chloritic material. Curiously enough, masses of quartz, sometimes with miarolitic cavities, are frequently found, not in the centre of an intersertal space but marginally, and in the neighbourhood of an augite crystal where such happens to form the wall, and to be devoid of a pegmatitic fringe. In such a case the quartz usually moulds the augite, and has apparently also corroded it to some slight extent, irregular portions of quartz being sometimes found embedded in the hornblendic margins of the augite.

It is evident that the fringes of linear micropegmatite have crystallised in regular series after the compound labradorite-oligoclase crystals, but it is equally evident that they were not always the last product of crystallisation. Masses of felspar or of quartz or a granular or cryptocrystalline aggregate of both may apparently succeed the micropegmatite in period. The fringes themselves frequently assume very beautiful forms, resembling in every respect the diagrams of "micropegmatite à étoilement" and

"quartz vermiculé" of Levy and Lacroix.* Where the growth has assumed a crystalline form, as occasionally happens within the intersertal spaces, it is invariably that of felspar, frequently simply twinned, and occasionally with an hour-glass structure similar to that found in augite.† Sometimes also the micropegmatite may be observed eating into the earlier columnar felspars, partially or wholly replacing one half of a narrow carlsbad twin, or attacking the earlier crystal in a number of isolated spots. The felspar of the micropegmatite has a refractive index commonly lower than that of the quartz, and is apparently always an alkali felspar. It is rarely found absolutely fresh. Usually it is much kaolinised, and it is, in fact, to the turbid condition of the mesostasis, sometimes stained with iron, that the grey or reddish colour of scattered portions of these rocks is largely due.

The Structure of the Diabases.

Two factors have apparently influenced the structure of the diabases, namely, the period of maximum crystallisation of the felspars and the amount of mesostasis at different points within the mass. Where the felspar has, on the whole, crystallised before the augite, while mesostasis is entirely absent or in exceedingly small amount, a true holocrystalline ophitic structure has been produced. This type, however, is comparatively rare, and mostly confined to the marginal portions of the larger sills. In the dykes by far the commonest type is that which may be described as intersertal-sub-ophitic, for the production of which a fair amount of mesostasis is required, and a slight extension of the period of the felspar both before and after that of the augite. Here the augite assumes the peculiar habit already described on p. 140. Where the bulk of the felspar has crystallised after the augite, and a large amount of mesostasis occurs, as in the central portions of the sills, both minerals develop long columnar forms. The augites may enclose marginally small early felspars, but, as a rule, they are moulded and more or less corroded by the later felspars. The large amount of mesostasis has here apparently given scope to the felspar to develop idiomorphic outlines wherever they did not come into close contact with the augite. A rude parallel arrangement of the columnar felspars and augites is sometimes to be observed in the interiors of the sills, and this, with the bending and breaking of the augites already referred to, is doubtless due to the effect of the pressure of the overlying rocks upon the partially solidified igneous material.

The Diabase Aphanites and Diabase Porphyrites.‡

Towards the margins of the dykes and sills the coarse-grained diabases pass gradually into compact, non-porphyritic aphanites, frequently spotted with dark green ocelli. At the contact itself the aphanites pass into exceedingly fine-grained and porphyritic basaltic varieties. Glassy modifications appear to be absent.

* Lacroix, *Minéralogie de la France*, vol. ii. p. 36. *Cf.* also "Myrmekitic Structure," Weinschenk, *Die gesteinsbildenden Mineralien*, p. 75.

† Flett, *Trans. Geol. Soc. Edin.*, vol. viii. p. 485.

‡ Zirkel, *Lehrbuch der Petrographie*, vol. ii. p. 699.

(*a*) *The Aphanites.*

The mineral composition of the aphanites is similar to that of the diabases. The felspars are rarely zoned, and the earlier formed basic varieties are usually more idiomorphic than the later acid types which assume very generally a ragged, elongated form. The augite may occur in the granulitic condition between or partially enclosed in the felspars, or it may build small ophitic plates and act as matrix. More rarely it develops a long prismatic branching form. (See Pl. III. fig. 1.) Occasionally in a section earlier formed glomero-porphyritic groups of augite and felspar may be detected by their compact structure. Paramorphism to hornblende is rare; chloritisation is more common. Magnetite occurs in skeletal networks. Pyrites is usually abundant, frequently in porous cubes. Olivine is occasionally found, but never bronzite. A little undifferentiated groundmass is sometimes present, also a little quartz, and very rarely a patch of granophyric material. The structure is minutely granular or ophitic according to the habit of the augite. Vacuoles of irregular shape, and filled with calcite, chlorite, and quartz, are common. (See Pl. III. fig. 2.) Many of these are probably not to be considered secondary in the ordinary sense of the word. It is frequently evident that the quartz has been formed by a molecular replacement of various minerals, especially felspar, and sometimes the ghosts of lath-shaped felspar can be seen outlined in the quartz by means of their original inclusions which have been preserved within the pseudomorph. The ocelli on the other hand represent primary steam-cavities, partially or wholly occupied by residual material leached out of the intersertal spaces during the final stages of consolidation.* (See Pl. III. fig. 3.) In nature they are essentially felspathic, being filled as a rule by an irregularly felted mass of slender, curving rods of felspar, acicular crystals of purple augite, usually undergoing decomposition, a little apatite and quartz, and frequently much pyrites in open porous crystals and irregular growths. One or more vacuoles, representing primary miarolitic cavities and filled with calcite, quartz, or chlorite, are usually present within the ocellus.

(*b*) *The Diabase Porphyrites.*

These occur at the contact, and are minutely porphyritic with olivine, augite, plagioclase, and glomero-porphyritic groups of augite and felspar. (See Pl. III. fig. 5.) The olivines are usually much corroded and decomposed. Much xenocrystic quartz with augite mantles is usually present, and probably derived from the adjoining sedimentary rocks. (See Pl. III. fig. 6.) Pyrites is frequently abundant in irregular granular masses or porous cubes. The groundmass is exceedingly fine-grained, and consists of microlites of felspar, granules of augite, much magnetite dust, and probably also a small quantity of undifferentiated material.

* Teall, *Geol. Mag.*, 1889, p. 481; Flett, *Trans. Roy. Soc. Edin.*, vol. xxxix., 1900, p. 865.

The Segregation Veins.

Two varieties of contemporaneous veins occur in the larger sills :—

(1) "Iron bands," reddish in colour, porous, with miarolitic spaces, and finer or coarser in texture than the surrounding rock;

(2) "Blue bands," fine-grained compact and dark-coloured, much resembling basalt, and usually rich in pyrites.

The composition of both is essentially felspathic, with a small quantity of acicular augite and a varying amount of quartz. A fluidal or trachytic arrangement of the lath-shaped felspars is very apparent in the finer-grained varieties. Augite is more abundant in the blue bands, and is usually much amphibolised and chloritised. The felspar is largely an oligoclase-andesine, much decomposed, although more acid varieties are probably also present. The amount of quartz varies within wide limits, and may sometimes be observed replacing the felspathic material. Pyrites appears to be most abundant in the blue bands. (See Pl. III. fig. 4.) The chemical composition is given below.

The Chemical Composition of the Diabases.

	I.	II.	III.	IV.	V.	VI.
Silica, ... SiO_2	48·02	59·33	56·22	51·80	64·54	71·26
Titanium dioxide, . . TiO_2	3·36	3·42			1·22	0·28
Alumina, . . . Al_2O_3	13·03	12·86	16·33	16·43	13·63	11·87
Phosphoric acid, . . P_2O_5	0·395	0·388			0·32	0·10
Ferrous oxide, . . FeO	9·99	6·46	7·94	10·64	4·83	2·12
Ferrous disulphide, . FeS_2	1·24	0·215	...	...	1·735	0·256
Ferric oxide, . . . Fe_2O_3	2·11	1·88	3·11	1·20	0·22	0·10
Manganous oxide, . . MnO	trace	0·14	0·11	0·39	0·20	0·06
Lime, ... CaO	9·77	3·74	5·63	4·13	2·31	2·88
Magnesia, . . . MgO	4·21	2·09	2·99	5·76	1·25	1·08
Potash, ... K_2O	0·49	2·15	1·65	0·85	2·28	0·054
Soda, ... Na_2O	2·17	5·13	3·84	3·81	5·21	6·73
Sulphuric oxide, . . SO_3	trace	...	...	...	trace	...
Fluorine, . . . F	0·058	0·044	...	...	0·056	0·009
Combined water, . .	4·27	2·12	1·63	3·89	1·86	2·71
Carbon dioxide, . .						
Moisture, . . .	1·05	0·48	0·88	1·47	0·84	0·62
	100·16	100·44	100·33	100·37	100·50	100·12

I. Dark-coloured modification, somewhat weathered, Kettlestoun Quarry.
II. Light-coloured felspathic modification, Kettlestoun Quarry.
III. Interior of Carribber sill, Carribber Quarry.
IV. Ocellar margin of Carribber sill, Carribber Glen.
V. Blue band, Carribber Quarry.
VI. Red band, Kettlestoun Quarry.

The amount of silica in adjoining portions of the sills (I., II.) may apparently vary as much as 10 per cent. The heavy metals vary inversely, and the alkalies directly as

the silica. The alumina alone remains fairly constant. The silica percentage decreases also towards the margins of the sills (III., IV.). This agrees very well with the results of other observers, although STECHER's figures for the Hound Pt. diabase led him to exactly the opposite conclusion.* The segregation veins are exceptionally rich in silica and alkalies.

CONCLUSION.

Three hypotheses have been advanced in explanation of the presence of an excess of silica in some diabasic rocks. The quartz of the Scottish quartz-bearing diabases was considered by STECHER entirely of foreign origin, and due to the fusion of portions of the adjacent sedimentary rocks caught up during intrusion and the assimilation of their constituents by the basic magma.† Later, the quartz was, on the analogy of quartz syenites and quartz-diorites, conceived as an original constituent of the intrusive magma;‡ while SOLLAS has explained its presence on the assumption of the injection of granophyric material into a previously solidified and porous diabase.§

STECHER's idea undoubtedly contains some element of truth, for xenocrystic quartz grains are frequently present on the margins of the sills. That the whole of the quartz-content can be of this origin is, however, very doubtful. The remains of portions of sandstones, shales, and limestones, which one would here expect to find, are rarely or never observed within the diabases, while the neighbouring basaltic intrusions which ought equally to possess such inclusions, are not only devoid of them, but of a micropegmatitic matrix as well.

Diabases with micropegmatite are a well-defined group of rocks, which occur in various parts of the world, intruded into rocks of very different character. Their constancy in composition and structure speaks more in favour of the primary igneous origin of all their constituents than of the later and more or less accidental origin of some of their ingredients. This remark applies alsc to SOLLAS' injection-theory, which, though demonstrated in some cases as a junction-phenomenon, is very difficult to apply to the case of the Linlithgow diabases. In the centres of the larger sills the micropegmatitic matrix in places makes up about two-thirds of the whole, and in some sections the columnar augites and felspars appear like porphyritic crystals in a granophyric groundmass. It is improbable that the interiors of the Carribber and Kettlestoun sills were ever occupied by such an exceedingly loose and open framework of augite and felspar as the injection-theory would here demand. Moreover, the segregation veins, so far as observed, are never themselves micropegmatitic, although formed out of the same constituents as the intersertal matrix.

On the whole, the facts are most easily explained on the hypothesis of the differentiation of a diabasic magma primarily charged with an excess of silica. The

* STECHER, *op. cit.* p. 161.

† *Tsch. Min. u. Petr. Mitth.*, vol. ix., 1887.

‡ TEALL, *Quart. Journ. Geol. Soc.*, vol. xl., 1884, pp. 209, 640: HARKER, *Ibid.*, vol. l., 1894, p. 311; vol. li. p. 125: HOLLAND, *Ibid.*, vol. liii., 1897, p. 405.

§ *Trans. Roy. Irish Acad.*, vol. xxx., 1894, p. 477.

differentiation has proceeded on lines similar to those described for closely allied rocks by TEALL, HARKER, and HOLLAND. The silica and alkalies tend to move inwards, and the ferromagnesians outwards. Consequently, the interiors of the intrusions are more acid than the margins. Where the differential movement has been local only, dark and light coloured modifications are produced, which are contrasted both in mineral and in chemical composition.

Whether the whole of the silica percentage should be claimed as primary is, however, open to question. The quartz, which is in intimate intergrowth with felspar, is probably wholly original, although in places peculiar ragged portions of quartz occur in the midst of linear micropegmatite and simulate very closely corrosion effects. Where the quartz forms simple masses however, especially in the vicinity of vacuoles and miarolitic cavities, some of it is undoubtedly of later origin. This is betrayed both by the nature of its inclusions and the occurrence of ghosts of felspar crystals, as already described, within the quartz. It is possible that this secondary quartz may be partly of aqueous and partly of pneumatolytic origin. That both the lavas and the diabases have been subjected to some extent to pneumatolytic action is fairly obvious. The occurrence of bituminous knots in the lavas, and the extensive zeolitisation and decomposition which some of them have suffered, are probably to be referred to such action. In the diabases, also, fairly good evidence is obtained in the peculiar late formation of pyrites in the ocelli and elsewhere.* It is just possible, therefore, that the deposition of free quartz, as well as the kaolinisation and sericitisation of the felspars and the amphibolisation and chloritisation of the augite, especially in the neighbourhood of miarolitic cavities, may have been to some small extent the result of the passage of steam and other gases through the porous rock after consolidation.

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* See WEINSCHENK, *Grundzüge der Gesteinskunde*, vol. i. p. 118.

EXPLANATION OF PLATES.

Plate I.

1. *Coarse-grained dolerite, N. Mains quarry.*—Portions of the rock are being replaced by a brownish granular substance, which passes later into analcite. The outlines of the lath-shaped felspars are sometimes, as in the figure, distinguishable within the pseudomorph.

2. *Fine-grained dolerite, Bo'ness.*—The rock is practically a holocrystalline aggregate of felspar, augite, olivine, and magnetite. Ophitic structure is not pronounced.

3. *Felspathic basalt, west of Redhouse.*—The porphyritic crystals here are olivines, round which the lath-shaped felspars are arranged in fluxion streams. The small idiomorphic augites are aggregated on the margins of the olivines, and in clumps between the felspars.

4. *Basalt, above limestone, The Knock.*—This rock is sparingly porphyritic, with small olivines and augites not very apparent in the figure. The groundmass is an intimate mixture of small felspar rods, idiomorphic augites, and grains of magnetite.

5. *Basalt, Cathlawchill quarry.*—Olivine, completely serpentinised, is here the only porphyritic constituent. The felspar of the groundmass is reduced in amount, and the crystals are irregularly arranged. The augite is aggregated into heaps and associated with a little glassy base.

6. *Basalt, Kipps Hill.*—The phenocrysts are olivine and augite. In the groundmass the felspars are few, the augite more abundant, and the brown, glassy base conspicuous.

Plate II.

1. *Ophitic diabase, Kettlestoun quarry.*—The augite is cloudy through formation of a brown, granular, isotropic dust. Above the centre is a mass of pyrites, and to the right streaks of the same mineral may be seen piercing a crystal of felspar.

2. *Diabase, Carribber quarry.*—The figure shows well the columnar habit which the felspars and augites assume in the centres of the larger sills. The augite is intimately associated with a skeletal growth of ilmenite, and is slightly amphibolised on the margins. The intersertal spaces are filled with micropegmatite. The clear space in the upper right-hand quadrant is an imperfection in the slide.

3. *Diabase, Carribber quarry.*—The augite is curved and broken and intergrown with ilmenite. The felspars are much decomposed, and the micropegmatitic matrix is abundant. The clear spaces are wants in the section.

4. *Diabase, Carribber quarry.*—The columnar felspars are much decomposed and surrounded by fringes of micropegmatite. The remainder of the intersertal material is made up of coarser intergrowths of quartz and felspar.

5. *Diabase, Carribber quarry.*—The figure gives details of the micropegmatitic mesostasis. In places it assumes a linear character and fringes the larger felspars. In others the quartz predominates in the intergrowth, and may appear in ragged growths within the linear material.

6. *Diabase, Carribber Reservoir.*—A pseudomorph of bastite replaces an original crystal of bronzite. This is associated with augite, felspar, ilmenite, and a small amount of intersertal material

Plate III.

1. *Diabase, Carribber quarry.*—This variety is somewhat finer grained and aphanitic, and encloses a branching augite studded with magnetite grains and rendered almost opaque by decomposition products. Below the augite is a portion of an ocellus with a vacuole.

2. *Diabase aphanite, Kettlestoun quarry.*—The aphanite occurs as a marginal modification of the sill. Three vacuoles are shown filled with quartz and calcite. The ragged character of their margins suggests a secondary origin. The edge of the section appears on the left.

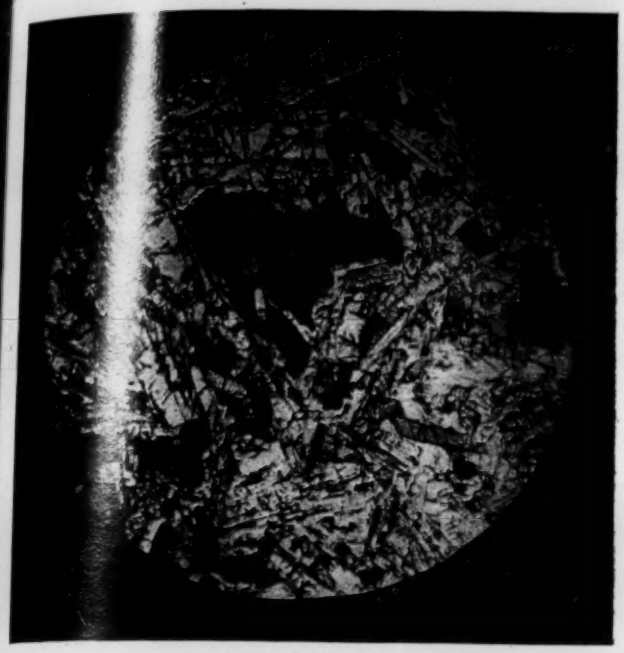
3. *Diabase aphanite, Kettlestoun quarry.*—The section is imperfect, but shows a portion of an ocellus primarily enclosed in aphanitic material. The ocellus is partially filled with a feathery, felspathic, and augitic growth, and abundant granular pyrites. The central vacuole is occupied by a mass of quartz and calcite.

4. *Segregation vein, Carribber quarry.*—The material of the vein is imperfectly marked off from the aphanite which encloses it. A porous growth of pyrites occurs in the middle of the vein.

5. *Diabase porphyrite, Dyke east of Cockleroy.*—Glomeroporphyritic groups and detached crystals of felspar, augite, and olivine occur in a groundmass of minute felspar, augite, and magnetite grains.

6. *Diabase porphyrite, Dyke east of Bangour Reservoir.*—The porphyritic crystals are felspar, augite, and olivine. Foreign quartz grains, with resorption borders, are abundant.

J. I FALCONER ON THE IGNEOUS GEOLOGY OF THE BATHGATE AND LINLITHGOW HILLS.
PART II. PETROGRAPHY. PLATE I.



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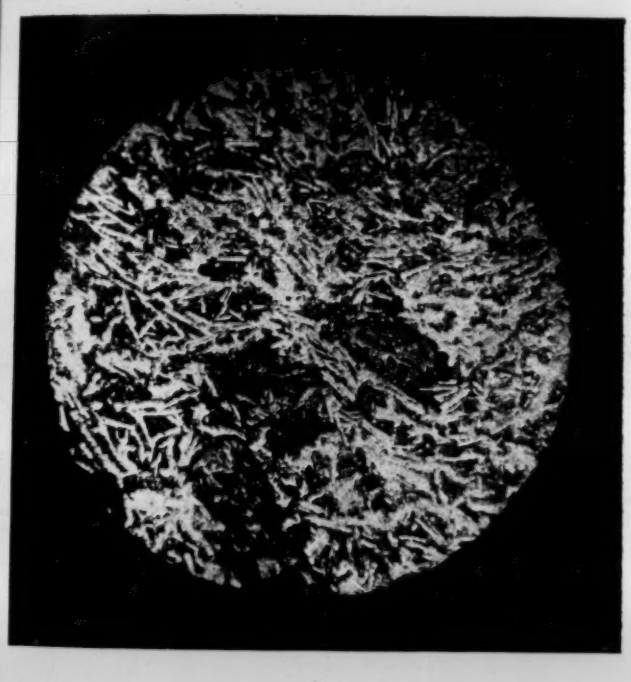

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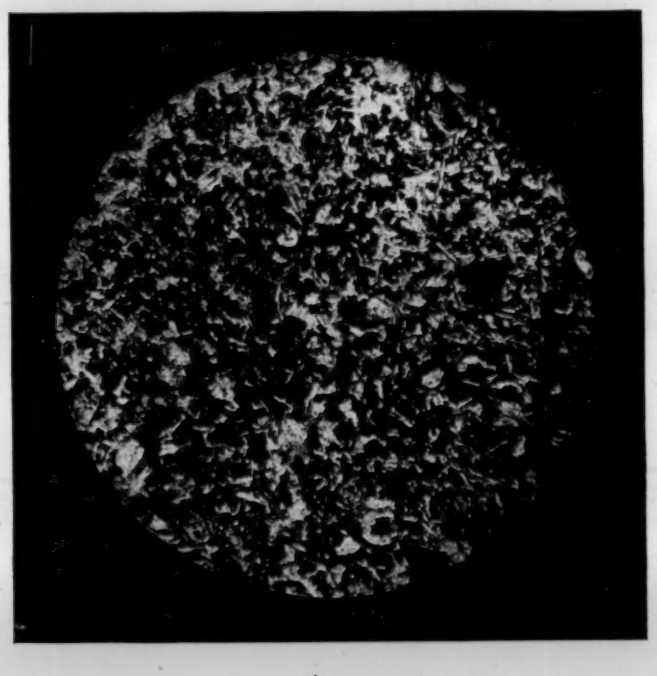

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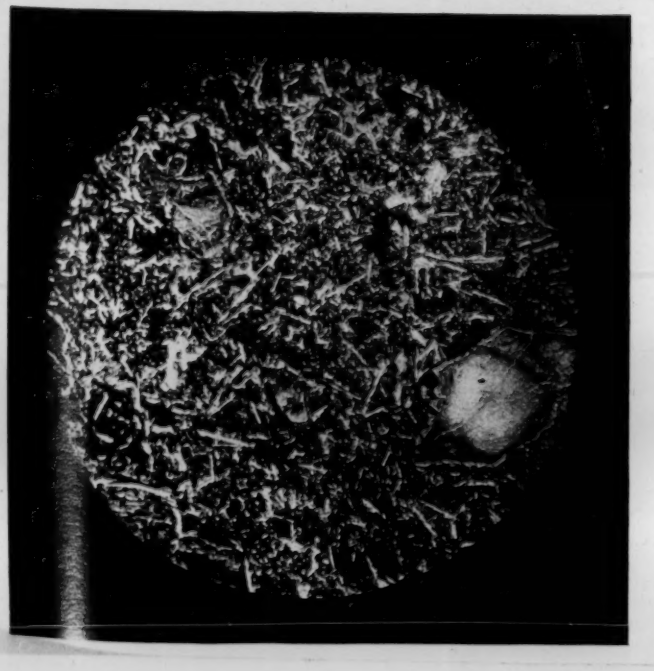

J. D. Falconer on the Igneous Geology of the Bathgate and Linlithgow Hills.
Part II. Petrography. Plate II.

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J. D. Falconer on the Igneous Geology of the Bathgate and Linlithgow Hills.
Part II. Petrography. Plate III.

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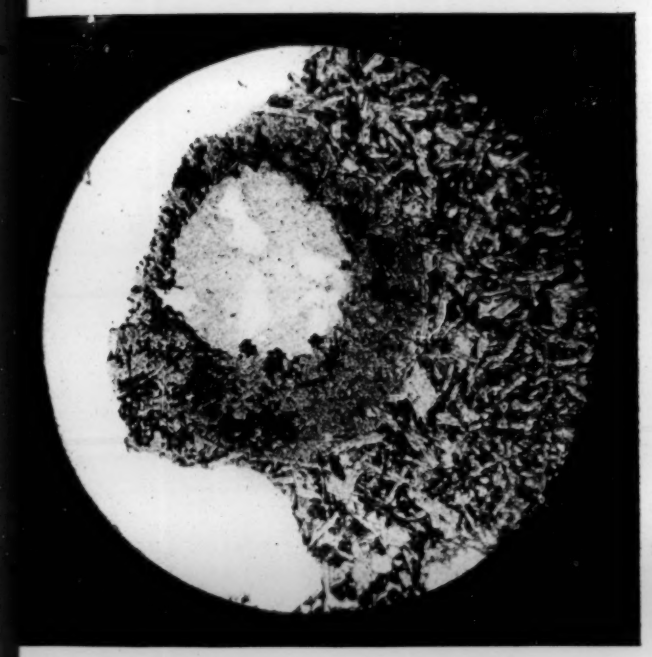

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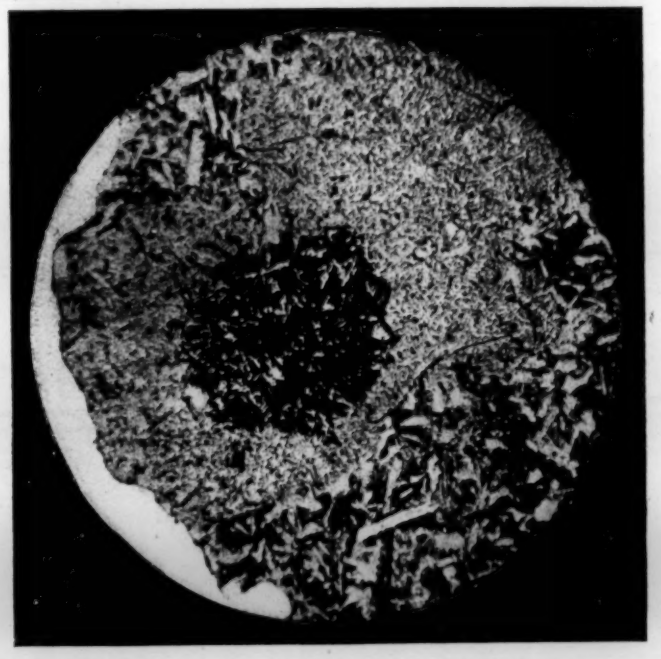

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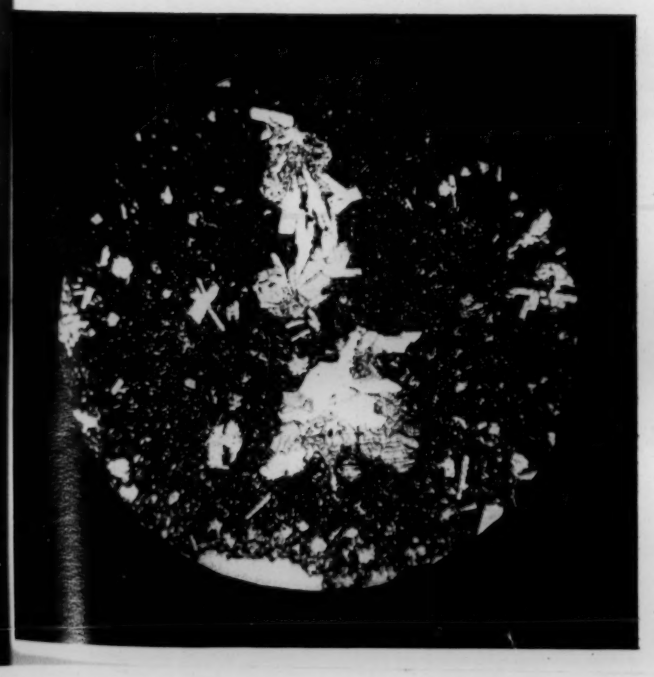

VII.—The Rotifera of the Scottish Lochs. By James Murray. Including descriptions of New Species by C. F. Rousselet, F.R.M.S., and D. Bryce, Esq. *Communicated by* Sir John Murray, K.C.B. (With Six Plates.)

(MS. received March 5, 1906. Read May 28, 1906. Issued separately June 14, 1906.)

Introduction.

A necessary preliminary to the study of the complex problems involved in the biology of lakes is to ascertain the facts. The collection of the bathymetrical data was begun many years ago by Sir John Murray and Mr Pullar, and is nearing completion under the Lake Survey. The next thing is to take a census of the inhabitants. This we are now trying to do by compiling lists of the animals and plants living in the lakes. The study of the problems after the data are collected falls outside the province of a lake survey, and within that of some permanent biological station. This present compilation is one step in the accumulation of the facts.

This list of Rotifera observed in the Scottish lochs makes no claim to be exhaustive. A glance over it will show, to those competent to judge, where it is deficient, and how unequal is the treatment of the three orders represented. Records by other observers are not included. Gosse records many Scotch Rotifers, some of them lacustrine; Messrs W. and G. S. West, in their plankton papers, Calman (11), and others, in various publications, have made mention of limnetic Rotifers. Messrs Scott and Lindsay (47) give a list of nearly 100 species from one small loch. To Hood, more especially, one of the pioneers of the study of the Rotifera, who has brought to our knowledge so many beautiful and interesting forms, must be credited the discovery of a great many species in Scottish lochs. Mr Hood's records, however, are often unlocalised, being set down simply as from lakes and ponds in Scotland; and inasmuch as the list, even with his and other workers' records included, would still be far from exhaustive, it is judged best to make this simply a list of species observed by the Lake Survey, a contribution to the knowledge of lake Rotifera.

The compiler of the list having made a special study of one order, the Bdelloida, that order is treated with greater fulness than the others; the Rhizota and Ploïma might easily be added to if qualified naturalists were to make a special study of our lakes. In those orders a great many more species than are here recorded were actually seen, but many could not be identified. A fourth order, the Scirtopoda, did not occur at all in our collections.

The number of Rotifera now known to science is very great. The 400 species, or thereabouts, known to Hudson and Gosse (22) in 1889 have been continuously added to since, and probably at the present time more than twice as many are on record. No

doubt a sifting of the synonymy would lead to an appreciable reduction in the number; but, after all allowance is made, the Rotifers remain a numerous group. As they are, in the words of JENNINGS (26), "potentially cosmopolitan," a large proportion of the species may be expected in any part of the world where extreme climatic conditions do not prevail, if time and care are given to the quest.

As all are aquatic animals, a classification of them in relation to their surroundings may be made, thus:—First, those which live in permanent fresh waters; second, those which live in stagnant water; third, those which live where the supply of moisture is intermittent (moss-dwellers); fourth, those which live in the sea. The lochs are themselves the headquarters for the species which prefer pure water. The Scottish lochs derive a large proportion of their water directly or indirectly from peat-bogs, and with this water there may be carried into the lochs numbers of the swamp or stagnant-water species, which in many cases seem to find the new conditions congenial; the moss-dwellers also readily find their way into the margins of lochs, and thrive there. The number of marine Rotifers known is relatively small, though it is probable that more discoveries await the patient investigator in this direction than in any other.

In view of the great variety of conditions which our lochs present, the purity and moderate range of temperature of the deep ones, and the summer stagnation and wide range of temperature of many of the shallow ones, it might reasonably be expected that a sufficiently long-continued investigation would lead to the discovery of the majority of known Rotifers. Yet our list numbers only 177 species. It must be borne in mind, however, that the examination of most of the lochs was only partial, in the great majority restricted to the plankton, and that our list is founded mainly on a careful study of a single loch, and that a deep one. A similar study of some of the shallow lochs would undoubtedly greatly swell the list. Few investigations of the Rotifera of lakes in which the shore and bottom regions are studied equally with the plankton are available for comparison. Naturalists working on the lakes of the Continent of Europe have for the most part confined their attention to the plankton.

From the published accounts at my disposal I select two which offer the closest parallel to our own inquiry. JENNINGS, in his *Rotatoria of the United States*, gives special attention to the Rotifera of the Great Lakes (26); STENROOS in 1899 published an account of the Rotifera of a single lake, the Nurmijärvi-See (48). A comparison of the lists given by these two investigators with our own might seem unfair, since STENROOS confined his work to one lake, JENNINGS to a few great lakes, while the Lake Survey examined many hundreds, great and small. The inequality to a great extent disappears when we consider that JENNINGS did most of his work and found the great majority of his species in one lake, Lake Erie, and the Lake Survey in like manner found most of the species in Loch Ness.

JENNINGS (26) gives a total of 164 species from the Great Lakes; STENROOS (48) found 157 species in Nurmijärvi-See; the Lake Survey here records 177 species from the Scottish lochs—a singularly close correspondence in numbers in all three cases.

When we scrutinise the three lists carefully, however, and observe how greatly they differ in detail, how much richer the American list is in Rhizota (though admittedly deficient in that order) than either of the others, how much more numerous are the Bdelloida in the Scotch list, and how very few the Rhizota, it becomes evident that the coincidence in numbers is purely fortuitous. The Rhizota are not deficient in the Scottish lochs—they are particularly abundant, as Mr HOOD's records show;* there is no reason to suppose that Bdelloids are scarce in the Great Lakes or in Finland—only that they have been less studied.

Confining the comparison of STENROOS's list to those compiled for the single lake most thoroughly examined by JENNINGS and by the Lake Survey, we see that the Finnish list is the most extensive. STENROOS got 157 species in Nurmijärvi-See, JENNINGS 132 in Lake Erie, the Lake Survey 148 in Loch Ness.

Loch Morar was visited several times, and 54 species were identified; 30 were noted in Loch Earn, 34 in Loch Tay. These numbers are merely an index to the time spent in the examination of the lochs, not to the number of species in them. There is no reason to doubt that the Rotifer-fauna of all our deep lakes is in the main identical; that of the shallow lakes on the whole richer, and locally more varied.

The classification of the Rotifera is in a chaotic state. Since the completion of HUDSON and GOSSE's monograph (22) in 1889, the number of known species has been doubled, and many of the new forms do not fit into the old divisions. New genera and families have been formed, and the old families redefined, to admit them; but a new monograph is now a desideratum, to bring all the diverse forms into one comprehensive view, and allot them their natural places. Most of the genera are in urgent need of revision. Excellent revisions of single groups have already been made by ROUSSELET, of *Synchæta* (46); DIXON-NUTTALL and FREEMAN, of *Diaschiza* (12); by JENNINGS, of the Rattulidæ (27); etc. Similar studies of most of the large genera would be a useful preliminary to the preparation of a monograph.

Most authors still continue to recognise, sometimes under protest, the unnatural suborders Loricata and Illoricata, though it would generally be admitted that the possession or lack of a lorica is properly only a specific, or at most a generic or family character. HUDSON and GOSSE's classification is here followed, with such additions as new discoveries require, and in the Bdelloida a radical redefinition of most of the genera, which, however, can only serve a temporary purpose.

In studying such an extensive group as the Rotifers, few can have the comprehensive knowledge possessed by ROUSSELET. Most workers will find it desirable to limit themselves to a special study of some smaller group. To such necessary limitation we may ascribe some of the deficiencies of this list. These have been to some extent made good by sending collections and sketches to specialists.

In the preparation of the list I have been greatly assisted by Messrs BRYCE and

* About half the known species of *Floscularia* were first discovered by Mr Hood in Scottish lochs, and of this genus alone he has found more species in the lochs than there are Rhizota in this list.

Rousselet, who have at all times been courteously willing to examine drawings and materials sent to them, and to give me the advantage of their judgment as to the value of species. I desire here to express my sense of the obligation they have conferred upon the Lake Survey. The Rotifers recorded for Loch Leven and Loch Gelly were collected by Mr Evans and identified by us.

In common with other groups of lacustrine animals, the Rotifera can be most conveniently studied by treating separately the species inhabiting each region of the lake—the pelagic region, the littoral region, and the abyssal region. The association of species constituting the plankton is very distinct, but of limited number: the littoral region is very rich; the abyssal, if it can be said to exist at all in Scotland, is very thinly populated, and distinguished by negative characters only.

Throughout the text, references to the bibliographical list at the end of the paper are made by figures in heavy type, enclosed in parentheses.

Pelagic Region.

It has been truly remarked by Dr C. Wesenberg Lund (34) that the Rotifera on the whole play but an inconspicuous part in the pelagic region of the larger lakes. The Scottish lakes form no exception to the rule. Nevertheless, the Rotifera must be accorded the second place in importance in the limnetic fauna, as, after the Crustacea, no class of animals except the Rotifera is habitually represented by several species in most, if not all, lakes. The number of species in each lake is small, and, as they are such minute animals, they must become exceedingly numerous before they can be conspicuous in the plankton.

Frequently in the smaller lochs, and perhaps occasionally in the larger ones also, though no instance of it has come under my notice in Scotland, one or more species will so increase as to be for the time being more conspicuous than any other organism in the lake. Species of *Synchæta* and *Asplanchna*, which are giants of their class, most frequently do this. In a little hill loch (L. Breachlaich) near Killin, in the early summer of 1903, *Asplanchna priodonta* was so abundant as to obscure all other life in the loch. After drawing our nets for the usual five minutes, a whitish slime filled the bottom of them, consisting solely of this animal. In a very small loch (Monk Myre) near Blairgowrie, the most truly limnetic of all Rotifers, *Notholca longispina*, coloured the collection (five minutes' tow-netting in a two-ounce bottle) dark red, and little else could be seen.

Sometimes a species, not usually regarded as truly limnetic, will greatly increase for a time in a small loch. In a little loch in Galloway (Loch of Cults), one of the most abundant animals in the plankton was *Polychætus collinsii* (Gosse). This phenomenon might conceivably occur in our great lakes, but has not been observed, and such swarming is probably prevented in them by the always moderate temperature.

The method of collecting the limnetic Rotifera is the simple one of drawing tow-nets

for a definite time through the open water of the lake, as far as convenient from the shore. It is advisable to draw them for a time at some distance below the surface, say 20 feet, as well as at the surface, because in extremes of weather the animals sometimes retire from the layer close to the surface. They should be examined as soon as possible after collecting, as most of them very quickly die under the changed conditions. While some will survive for a time in the bottles, others, such as *Notholca longispina*, are so sensitive to change of temperature that they are seldom found alive when the collections are brought home.

Although very many Rotifera are free-swimming, comparatively few are limnetic, albeit, if the whole world is taken into account, the number is considerable. By limnetic Rotifers is meant such species as normally take up their position, far from the shelter of plants, in the open water of the lake, and extend to every part of it.

Of the truly limnetic Rotifera, few occur together in any one lake; their range may be world-wide, but their distribution is local. A species regarded as limnetic in one part of the world may be only known as an inhabitant of the lake-margins elsewhere. It is well to distinguish, among the limnetic species of one lake or district, between these more or less local species, and the others which belong to that universal association of limnetic animals which are present in all lakes offering normal conditions.

Dr Lund, in the paper above cited (34), gives a short list of species which he characterises as "the cosmopolitan stock of plankton Rotifers." These are *Polyarthra platyptera*, *Synchæta* sp., *Asplanchna priodonta*, *Anuræa cochlearis*, *Anuræa aculeata*, *Notholca longispina*, *Conochilus unicornis*, and *Triarthra longiseta*.

On the whole, Dr Lund's list embodies the species which we find to be most generally distributed in the Scottish lochs. Inasmuch, however, as it is difficult to avoid generalising from partial data, it may be useful if we examine Dr Lund's list in the light of our experience in the Scottish lochs, and indicate some points to which we must take exception.

Scotland is pre-eminently a country of lakes. Considering its situation in a temperate region, the great number of its lakes, many of which, though not of great extent, are from their depth to be classed among great lakes, we would be justified in regarding Scotland as favourable for the existence of the cosmopolitan stock of Rotifers. We would expect to find this stock in all our greater lakes; we would at the least expect that no member of it would be absent or rare. The fact that five out of Dr Lund's eight cosmopolitan species are our commonest limnetic species shows that Scotland is suitable for them. These five most thoroughly limnetic species are *Polyarthra platyptera*, *Asplanchna priodonta*, *Anuræa cochlearis*, *Notholca longispina*, and *Conochilus unicornis*.

Let us now consider the three species which do not live up to their cosmopolitan character in Scotland.

Synchæta sp. is unsatisfactory, as Dr Lund does not name the species which he regards as cosmopolitan. Various species of *Synchæta*, especially *S. pectinata* and

S. tremula, are common in our small lakes; some of the other species may affect more particularly larger lakes; but no one species is general in the lakes, and it is not by any means the case that any *Synchæta* is invariably present. Many lakes have normally no *Synchæta*. I am inclined to regard all the Synchætadæ, like all the Plœsomadæ, as local species.

Triarthra longiseta is more difficult to deal with. It looks a thoroughly limnetic animal; it has a wide distribution in Scotland; and, being more frequently seen in winter and early spring, it may have been overlooked in some lochs, and may be commoner than we know. Still, the fact remains that we have only seen it in some twenty-four lochs, and of these only five are moderately deep, while it is absent from all our greatest lochs. It is less common than *Gastropus stylifer* and *Floscularia pelagica*, which are considered local species. While I am not prepared to trace the universal distribution of the species in lakes, I would point out two facts which confirm our experience of it.

Jennings (26) does not indicate that it is one of the common limnetic species in the Great Lakes, giving only one record, from Sandusky Bay. Zacharias (56) describes a var. *limnetica*, implying that the type is not limnetic; but the variety appears to be rare. The species is found in the plankton lists of many European biologists, but it must be remembered that most of the biological stations are established on shallow lakes.

As to *Anuræa aculeata*, our experience runs quite counter to Dr Lund's. The species has not, to my knowledge, ever occurred in a purely limnetic collection from any lake in Scotland. The type of the species is rare even in littoral collections. Several varieties—*A. serrulata*, *A. brevispina*, and *A. valga*—are of more frequent occurrence among weeds. Of these *A. valga* is most nearly limnetic, being abundant in the plankton of a number of small and shallow lakes; but it also is absent from the larger lakes. As in the case of *Triarthra longiseta*, Jennings' (26) few records indicate that it is not a common lacustrine species in America. As to its presence in the plankton of many European lakes, the same remarks apply as to *Triarthra*.

Besides the five cosmopolitan plankton Rotifers, there have been observed in the Scottish lochs a number of other species, as thoroughly limnetic, but of more local distribution. These are *Floscularia pelagica*, *Floscularia mutabilis*, *Triarthra longiseta*, *Polyarthra euryptera*, *Synchæta pectinata*, *Synchæta tremula*, *Gastropus stylifer*, *Plœsoma hudsoni*, *Plœsoma truncatum*, *Anapus testudo*, and *Conochilus volvox*.

Proales (*Hertwigia*) *parasita*, though not itself limnetic, is carried with its host (*Volvox*) into the open water of many lakes, and some even of our great lakes.

Gastropus stylifer is the commonest of these species. It has been found in about seventy lochs distributed over the whole of the mainland and islands.

Conochilus volvox may be as common, or even more common; but, as it is not so easily recognisable when dead and contracted, we have fewer records for it. It is widely distributed.

Plœsoma, of one species or another, is of general occurrence all over the country, but we were unable to identify the species in so many of the lochs that the distribution cannot be traced. *P. hudsoni* was the commonest species in the islands, but was also found here and there on the mainland, where, however, some smaller species were commoner.

Floscularia pelagica is widely distributed on the mainland, and occurs in Shetland, but was not observed in the Hebrides. Though only recorded from some thirty lochs, it is probably much commoner, as it would readily be overlooked in preserved collections. *Triarthra longiseta* was noted in some twenty-four lochs in Caithness, Sutherland, Ross, Inverness, Edinburgh district, and Galloway. It was not seen in the islands.

We have thus some sixteen species of truly limnetic Rotifers. Many other more or less pelagic species have been found, but they are confined to little lochs or the weedy bays of the larger ones, and cannot with us be called limnetic. A large number of littoral species have occurred casually in the plankton collections, even to such heavy-bodied creepers as *Philodina rugosa* and *P. laticeps*.

Mr Hood, in a recent letter, gives some information as to the seasons when the species of *Plœsoma* are found, and mentions two species which were not identified in any of the Lake Survey collections. The two additional species are *Anarthra aptera*, Hood (19 and 21), and *Plœsoma lenticulare* (18). *Plœsoma hudsoni* he finds from May to August, *P. truncatum* from June to October, *P. lenticulare* from July to September.

Many Continental naturalists give longer lists of plankton Rotifers from limited districts or single lakes than are recorded for the very numerous lakes of Scotland. It is well to bear in mind that most of the biological stations are situated on the shallower lakes, and that the plankton lists include species which are not limnetic in this country.

Dr Lund (32) records twenty-four Rotifers from the plankton of the Danish lakes, ten or twelve of which are littoral species with us. Apstein (1) records twenty-three species from the lakes of Holstein, eight or ten of which are not limnetic in Scotland.

On the other hand, Forel (14) has noted just fifteen species in the great Lake of Geneva; Stenroos (48), eight in Nurmijärvi-See; and Jennings (26), twelve species in Lake Erie, all of which are limnetic according to our definition.

The limnetic Rotifers, in common with the other pelagic organisms, extend through all the open waters of the lake, right in to the shore, and frequently occur in the washings of the littoral plants; they also often occur in ponds. The limnetic region is not characterised by the possession of any species peculiar to itself, but rather by the absence of the majority of the littoral forms, even such as swim freely, and the extension into it of a limited number of species which are especially independent of shelter. The limnetic and the abyssal regions have this in common, that they are in Scotland distinguished by negative rather than positive characters.

How far the limnetic Rotifers extend beneath the surface of the lake is unknown; we have no data as to the vertical range of the plankton organisms, except for some of the larger Entomostraca.

Littoral Region.

While plankton collections have been made in hundreds of lochs, it has only been possible to examine the littoral region carefully in a few lochs, about twenty-four in number. These are, however, fairly representative, including several of the great lakes, while the smaller ones selected for examination are widely scattered over the whole country from Galloway to Inverness and the Outer Hebrides. It is thus to be hoped that we have obtained a fair idea of the ordinary Rotifer-fauna of our lake-margins.

For the collection of the littoral Rotifers a special method has been devised, which has given satisfactory results. The object is to obtain the Rotifers and other microscopic animals free from débris or larger animals. Water plants of any kind, especially mosses and the finer-leaved flowering plants, are collected along the margin of the lake. They are placed inside a conical net of No. 6 Swiss bolting silk (an ordinary tow-net). This is put inside another net of very fine silk (say No. 17 to 20). The whole is then immersed in the loch with the rims of the nets an inch or two above the surface. The water weeds are then stirred and shaken about and washed in the nets as a bucket, in order to detach the organisms which adhere to them.

The plants are then thrown away, and the coarse net lifted out of the fine one and allowed to drip into it. We then have in the fine net only microscopic organisms and fine sediment. The contents of the coarse net may be examined for worms, Entomostraca, etc.

It has been found by experience that even very large Rotifers will readily pass through the No. 6 net. Possibly giants like *Stephanoceros* would not pass through, but such animals are found by the direct examination of portions of water plants under the microscope.

All water plants will repay examination. Aquatic mosses, such as *Fontinalis* and *Cinclidotus*, semi-aquatic, like *Grimmia apocarpa* and the various species of *Rhacomitrium*, and hepatics will be found to yield the greatest variety. Smooth plants like *Nymphæa*, *Potamogeton*, etc., frequently support numbers of Rhizota, but little else. *Myriophyllum* is sometimes good, especially for Rhizota and Bdelloida. It frequently becomes covered by a slimy growth of diatoms, and is then apparently distasteful to animals, as few or no animals other than Nematodes are found. *Chara*, when free of lime, is fairly productive.

Fontinalis is undoubtedly best of all. The large concave leaves offer just the kind of shelter that Rotifers like, while still it is not too contracted for the many species which enjoy a short swim if it can be taken in safety. *Fontinalis* has never failed to yield a fair harvest, except in the rare case when the lochs get so low that the moss is heated by the sun.

An average collection of littoral Rotifers, made in the manner described above, will contain a large number of species, among which the most prominent genera are likely to be *Euchlanis*, *Cathypna*, *Monostyla*, *Metopidia*, *Colurus*, *Notommata*, *Furcularia*,

Diglena, *Diaschiza*, *Diurella*, *Philodina*, and *Callidina*. These genera constitute the characteristic Rotifer-fauna of lake-margins; other genera, though common enough, are more casual in their occurrence. There are several species of each of these genera common in the littoral region, though none of them are confined to lakes.

It is in the littoral region that the richest Rotifer-fauna is found; in fact, the whole Rotifer population of a lake may be ascertained from the marginal collections, as the limnetic and the abyssal species here meet and mingle with the proper littoral forms. Including the casual as well as the permanent inhabitants, a large number may occur in any one lake. We observed 148 species in Loch Ness—undoubtedly far under the true number—and STENROOS noted 157 in Nurmijärvi-See.

From sixty to eighty of these species may be considered as of ordinary occurrence in lakes, and likely to be found in any lake which is carefully examined. The others are more local and uncertain.

Although by far the most densely peopled part of the lake, the littoral region has not the most marked lacustrine character. It is the few limnetic species which are most truly characteristic of lakes. Although the limnetic Rotifers also occur in ponds, their special characteristics are such as fit them for lake life. These characteristics—spines, transparency, free-swimming, etc.—have probably had their full development in lakes, though the animals now often extend into smaller waters.

The littoral Rotifers are none of them confined to lakes; they may be found in moist places anywhere—in ponds, bogs, streams, and among moss. Nevertheless, even the littoral region has a certain lacustrine character.

Leaving out of account some very shallow lochs and certain bodies of contaminated water near towns, the water of our lochs is, on the whole, pure, if peaty, and the genera given above as most common in lakes are those which have a preference for clear water.

A small number of species may be cited as pre-eminently characteristic of pure lakes, though not exclusively lacustrine. Most of them are Bdelloids. They are *Microdina paradoxa*, *Philodina flaviceps*, *P. brevipes*, *Furcularia reinhardti*, and *Euchlanis lyra*.

The shallow, weedy bays of the larger lochs, such as Inchnacardoch Bay in Loch Ness, afford much the same breeding-grounds for Rotifers as ponds and bogs, and it is in such bays that most of the casual species occur. Here we find swamp Rotifers, Rotifers from streams, and moss-dwellers casually introduced, all flourishing together.

There is one important distinction between such bays and ponds or swamps, which probably accounts for the number of casual species being smaller than might be expected. So long as these bays are in open communication with the deep water of the lake, a moderate temperature is maintained. Inchnacardoch Bay was never more than a trifling degree warmer than the centre of Loch Ness.

The distinction drawn by JENNINGS (26) between swamp and lake Rotifers is as clearly marked here, when such bays become in dry seasons completely cut off from the loch. Such a case is found in an extensive swampy stretch in Burlom Bay, Loch Ness.

When the level of Loch Ness is high this forms a mere bay, having the temperature of the rest of the lake, and all the usual lacustrine animals. In summer it is quite cut off from the loch, becomes greatly heated, and has a stagnant-water fauna distinct from that of the lake.

The littoral Rotifera in Loch Ness had a very distinct winter maximum development. They began to be abundant in December, reached the maximum in February, after which there was a steady and great decline. Many species, notably *Cathypna ligona*, were only seen during the few winter months; others were in the loch all the year round, but increased greatly in numbers in winter. This cycle was traced during two seasons.

Abyssal Region.

As I have already pointed out (40), the limited researches made by the Lake Survey have not revealed in the Scottish lochs any peculiar abyssal organisms whatever, except some Rhizopods which Dr Penard regards as peculiar to great lakes (41, 42). Many Rotifers do, however, extend from the littoral region into what would elsewhere be designated the abyssal region—although that term has no biological significance with us, in the sense in which Forel uses it (14).

Our knowledge of the vertical range of the littoral Rotifers is based on observations in Loch Ness. There alone have our studies been carried on for a sufficiently long time to justify us in supposing that we have a fairly adequate knowledge of the life of the abyssal region. A few species have been got in the mud of other lochs (*i.e.* Loch Rannoch, Loch Oich) at moderate depths. In Loch Ness, dredgings have been made with sufficiently fine nets at all depths down to 700 feet, and often enough to lead us to suppose that if Rotifers were abundant we would have found them. Rotifers were abundant at depths of less than 100 feet. Beyond that depth they became rarer as the depth increased, down to 300 feet, after which they dropped out altogether: only on one occasion was a single species, *Proales daphnicola*, found parasitic upon a worm at 500 feet. Between 250 feet and 300 feet the fine net on several occasions brought up numerous Rotifers, of about twenty species. Dredgings at those depths were unequal, often containing no Rotifers at all. All the Rotifers were of common littoral species. As it is of some interest to know what species are most capable of adapting themselves to varying conditions of light, temperature, pressure, etc., the complete list is given of all the species found at depths exceeding 250 feet:—

Philodina macrostyla, and the form *tuberculata*.
Eosphora najas.
„ *digitata*.
Diglena uncinata.
Diurella tenuior.
Diaschiza tenuior.
Euchlanis deflexa.
„ *lyra*.
Monostyla lunaris.
Dinocharis tetractis.
Metopidia acuminata.
„ *solidus*.
„ *triptera*.
„ *oxysternum*.
Colurus obtusus.
Proales daphnicola.

Several other species were found which we failed to identify.

The commonest animal in these deeper dredgings was *Diglena uncinata*. The typical form of *Dinocharis tetractis* was rare; but a variety, having the foot-spurs nearly or quite obsolete, was abundant. Several forms of *Eosphora* differed more or less from the types of the two species mentioned.

There is little difficulty in accounting for the presence of these species at such depths. They are all common along the shores of the loch. These shores in many places are very steep, and it is easy to understand how animals which feed among the mud may readily get deeper and deeper. They all feed on organic débris, and such food is brought in abundance to these depths by the rivers, or falls down the steep slopes.

In Loch Rannoch, *Philodina macrostyla* was dredged at a depth of 85 feet, but no Rotifers were found in the greater depths of that loch.

The abyssal region in Loch Ness can only be defined by negative characters; it lacks the majority of the littoral species. The littoral fauna gradually thins out as we descend, till a certain depth is reached, beyond which only a few species survive, and these extend to every part of the lake-bottom. Thus defined, we may say that there are no abyssal Rotifers in Loch Ness, as no species extends all over the bottom, as do *Cyclops gigas*, *Pisidium*, *Candone*, and the rest.

As Dr PENARD points out, in dealing with the Rhizopods (42), Scotland has many other lakes, and we may yet discover in some of these the abyssal fauna and the relict fauna of which we have as yet got no trace. Up to the present the indications are against this expectation: north (in Loch Ness) and south (in St Mary's) there is the same abyssal poverty.

LIST OF SPECIES.

Order RHIZOTA.

Family FLOSCULARIADÆ.

Floscularia campanulata, Dobie. Loch Ness.
,, *ornata*, Ehr.
,, *pelagica*, Rousselet (43). Widely distributed.
Floscularia mutabilis, Bolton. Loch Morar.
Stephanoceros eichhorni, Ehr. Loch Ness, rare.

Family MELICERTADÆ.

Œcistes crystallinus, Ehr. Loch Ness.
,, *brachiatus*, Huds. Loch Ness (abundant), Loch Tay.
,, *serpentinus*, Gosse. Loch Ness, one example.
Pseudœcistes rotifer, Stenroos (48). Loch Ness.
Conochilus volvox, Ehr. Generally distributed.
,, *unicornis*, Rousselet. Common everywhere.

Order BDELLOIDA.

Family MICRODINADÆ.

Microdina paradoxa, Murray (39). Frequent.

Family PHILODINADÆ.

Philodina :—A. Oviparous, eyes cervical.

Philodina roseola, Ehr. Lochs Morar, Nan Lann, and Duntelchaig.
„ *citrina*, Ehr. Lochs Ness, Nan Lann, Lochy, Morar, Tay, St Mary's, and Kinder.
„ *erythrophthalma*, Ehr. Lochs Ness and Morar.
„ *megalotrocha*, Ehr. Lochs Ness, Uanagan, Tay, Vennachar, An Duin, and Balnagown.
„ *brevipes*, Murray (37). Lochs Ness, Morar, Tay, and Vennachar.
Philodina flaviceps, n. sp., Bryce. Common everywhere.
„ *nemoralis*, Bryce (9). Lochs Ness, Nan Lann, and Killin.
„ *decurvicornis*, Murray (37). Loch Ness, rare.
„ *acuticornis*, Murray (37). Lochs Ness, Killin, Morar, Treig, and Earn.
„ *rugosa*, Bryce (9). Lochs Ness, Morar, Treig, and Earn.

B. Oviparous, eyes absent.

Philodina plena (Bryce) (7). Lochs Morar, Treig, and Earn.
„ *alpium* (Ehr.) (7). Lochs Ness, Lochy, Morar, Tay, and Earn.
„ *brycei* (Weber) (52). Lochs Ness, Uanagan, Morar, Treig, and Balnagown.
Philodina humerosa, Murray (39). Lochs Ness and Earn.
„ *hamata*, n. sp. On *Gammarus*, Lochs Tay and St Mary's.
„ *laticeps*, Murray (39). On insect larvæ and *Gammarus*, Lochs Ness, Uanagan, St Mary's, and Skeen.

C. Viviparous, eyes present or absent.

Philodina laticornis, Murray (39). (An exception, really related to *P. laticeps*.) Lochs Ness and Lochy.
„ *macrostyla*, Ehr. Lochs Burraland, Shin, Ness, Uanagan, Morar, Chon, and Kinder; var. *tuberculata* (Gosse), Lochs Rannoch, Ness, and Uanagan.
Philodina aculeata, Ehr. Lochs Ness, Nan Lann, Morar, and Tay.

Callidina :—A. Food moulded into pellets.

Callidina hexodonta (Bergendal) (2). Loch Ness.
„ *rœperi* (Milne) (36). Loch Treig.
„ *elegans*, Ehr.* Lochs Ness and Uanagan.
„ *angusticollis*, Murray (39). Lochs Morar and Ness.
„ *pusilla*, Bryce (6). Loch Morar; var. *textrix* (8), Lochs Ness and Morar (Bryce).
„ *longiceps*, n. sp. Loch Morar.
Callidina leitgebii, Zelinka? (57). Lochs Ness and Earn.
„ *annulata*, Murray (39). Lochs Morar and Earn.
„ *aspera*, Bryce (5). Lochs Ness and Morar.
„ *crenata*, Murray (39). Loch Earn.
„ *lata*, Bryce (5). Lochs Ness, Morar, and Leven.
„ *pulchra*, Murray (39). Loch Ness.

* A mistaken identification, really an undescribed species.

B. Toes three, distinct, no pellets.

Callidina plicata, Bryce (5). Common everywhere.
„ *quadricornifera*, Milne (35). Common everywhere.
„ *habita*, Bryce (7). Lochs Ness, Morar, Gelly (Evans), var. *bullata*, n. var. Murray. Loch Treig.
„ *ehrenbergii*, Janson (24). Lochs Ness, Morar, Tay.
Callidina papillosa, Thompson (49). Lochs Ness, Morar, Tay, Earn, Lomond; Leven and Gelly (Evans).
„ *multispinosa*, Thompson (49). Loch Shin; Loch Gelly (Evans).
„ *aculeata*, Milne (35). Loch Ness.
„ *muricata*, Murray (39). Loch Ness.
„ *crucicornis*, Murray (39). Loch Rannoch.

C. Foot ending in perforate disc.

Callidina symbiotica, Zel. (57). Lochs Ness and Earn.
„ *armata*, Murray (39). Loch Ness.
„ *tetraodon*, Ehr. Lochs Ness, Morar, and Earn.
Callidina russeola, Zel. (58). Lochs Ness and Morar.
„ *magna*, Plate. Loch Ness.

Rotifer.

Rotifer vulgaris, Schrank. Loch Ness, Lochans on Carnahoulin.
„ *neptunius*, Milne (35). Loch Ness.
„ *citrinus*, Ehr. Loch Gelly (Evans).
„ *tardus*, Ehr. Loch Ness.
Rotifer longirostris (Janson) (24). Lochs Morar, Balnagown, Gelly (Evans).
„ *trisecatus*, Weber (51). Loch Ness.
„ *macroceros*, Gosse. Loch Ness.
„ *socialis* (Kellicott). Loch Ness.

Family Adinetadæ.

Adineta vaga, Davis, var. *minor* Bryce. Lochs Ness and Treig; var. *major* Bryce. Lochs Ness, Lochy, Morar, Leven (Evans).
„ *gracilis*, Janson (24). Lochs Ness, Morar, Tay, Earn.
Adineta barbata, Janson (24). Lochs Ness and Earn.
„ *tuberculosa*, Janson (24). Lochs Ness and Earn.

Order PLOÏMA.

Family Microcodidæ.

Microcodon clavus, Ehr. Loch Ness.
Microcodides chlæna, Gosse. Loch Ness.
Microcodides robustus (Glascott) (16), (44). Loch Ness.

Family Asplanchnadæ.

Asplanchna priodonta, Gosse. Everywhere.
Ascomorpha ecaudis, Perty. Loch Ness.

Family Synchætadæ.

Synchæta pectinata, Ehr. Lochs Ghriama, Moine, Chaluim, Bi, Suardalain, Dilate.
Synchæta tremula, Ehr. Lochs Ness, Garbh, Swanney.

Family Triarthradæ.

Polyarthra platyptera, Ehr. Universal.
„ *euryptera* (Wier) (53). Lochs Tingwall, Kilcheran, Black (Argyle), and N. and W. Islands.
Triarthra longiseta, Ehr. Widely distributed. Noted in over 20 lochs; details under Pelagic Rotifera.

Family Hydatinadæ.

Notops hyptopus, Ehr. Loch Ness.

Family Notommatadæ.

Albertia intrusor, Gosse. Loch Ness.
Taphrocampa annulosa, Gosse. Lochs Shin, Ness.
„ *selenura*, Gosse. Loch Ness.
Notommata aurita, Ehr. Loch Ness.
„ *brachyota*, Ehr. Loch Ness.
„ *tripus*, Ehr. Loch Ness.
„ *torulosa*, Duj. Loch Ness (Rousselet).
„ *pumila*, n. sp., Rousselet. Loch Ness.
„ *forcipata*, Gosse. Loch Ness.
Copeus cerberus, Gosse. Loch Ness.
„ *spicatus*, Huds. Loch Morar.
„ *caudatus*, Collins. Loch Ness.
Proales petromyzon, Ehr. Loch Ness.
„ *parasita*, Ehr. Lochs Ness and Magillie, in *Volvox*.
„ *caudata*, Bilfinger. Loch Ness. Identified by Rousselet, from drawing.
„ *sordida*, Gosse. Loch Ness. Identified by Rousselet, from drawing.
„ *daphnicola* (Thompson). Loch Ness, on worm dredged at depth of 500 ft.
Pleurotrocha parasitica, Jennings (26). Loch Ness.
Furcularia longiseta, Ehr. Loch Ness; var. *æqualis* (Ehr.). Loch Morar.
„ *reinhardti*, Ehr. Loch Ness (Rousselet), Lochs Rannoch, Vennachar, Morar, Earn.
„ *forficula*, Ehr. Lochs Earn and Uanagan.
„ *quadrangularis* (Glascott). Lochs Ness and Tay.
Eosphora najas, Ehr. Loch Ness.
„ *digitata*, Ehr. Loch Ness.
Diglena grandis, Gosse. Loch Ness.
„ *forcipata*, Ehr. Lochs Ness, Uanagan, Morar, Tay.
„ *circinator*, Gosse. Loch Ness.
„ *ferox*, Western. Loch Ness. Identified by Rousselet, from drawing.
„ *uncinata*, Milne. Loch Ness.
„ *dromius*, Glascott (16). Loch Ness.

Family Rattulidæ.

Rattulus lophoessus (Gosse). Loch Ness.
„ *longiseta*, Schrank. Lochs Ness, Dochfour, and Dhu.
„ *scipio* (Gosse). Lochs Ness and Meide.
Diurella porcellus (Gosse). Lochs Ness and Earn.
„ *brachyura* (Gosse). Loch Ness.
„ *tenuior* (Gosse). Lochs Ness and Geireann.
„ *tigris*, Müller. Loch Ness.

Family Dinocharidæ.

Dinocharis tetractis, Ehr. Lochs Ness, Morar, Rannoch, Tay, Gulbin, Bhaic, Shin, and Chaluim.
„ *similis*, Stenroos (48). Loch Ness.
„ *pocillum*, Ehr. Lochs Ness and Tay.
Polychætus collinsii, Gosse. Lochs Chaluim, Cults, Morar.
Polychætus subquadratus, Perty. Loch Culag.
Scaridium longicaudatum, Ehr. Lochs Ness and Uanagan.
Stephanops stylatus, Milne (35). Lochs Ness, Morar, Lomond.
„ *tenellus*, Bryce (8). Loch Ness.

Family Salpinadæ.

Diaschiza gibba (Ehr.). Lochs Ness, Tay, Earn, Kinder, Shin, Lochans on Carnahoulin.
„ *tenuior*, Gosse. Loch Ness.
„ *sterea*, Gosse. Loch Morar.
„ *lacinulata* (Müller). Loch Ness.
Diaschiza ventripes, Dixon-Nuttall. Loch Ness.
„ *hoodii*, Gosse. Loch Ness.
„ *tenuiseta*, Burn. Loch Ness, 1 example.
Salpina mucronata, Ehr. Loch Balnagown.
„ *mutica*, Perty. Loch Uanagan.

Family Euchlanidæ.

Euchlanis lyra, Huds. Lochs Ness, Morar, Rannoch, Tay, Earn, Chaluim.
„ *oropha*, Gosse. Lochs Morar, Ness, Tay.
Euchlanis dilatata, Ehr. Lochs Morar, Ness, Tay.
„ *deflexa*, Gosse. Lochs Ness and Earn.
„ *triquetra*, Ehr. Lochs Rannoch, Lyon, Ness.

Family Cathypnadæ.

Cathypna luna, Ehr. Loch Ness.
„ *rusticula*, Gosse. Loch Ness.
„ *ligona*, Dunlop (13). Loch Ness, abundant.
„ *latifrons*, Gosse. Loch Ness.
Distyla flexilis, Gosse. Lochs Rannoch, Ness, Earn.
Distyla depressa, Bryce. Loch Ness.
Monostyla lunaris, Ehr. Lochs Ness, Morar, Tay, Earn, Kinder.
„ *cornuta*, Ehr. Lochs Ness, Uanagan, Morar, Lomond.
„ *bulla*, Gosse. Loch Ness.

Family Coluridæ.

Metopidia lepadella (Ehr.). Lochs Ness, Nan Lann, Uanagan, Ghlas, Earn.
„ *solidus*, Gosse. Lochs Morar, Earn, Ness, Tay.
„ *rhomboides*, Gosse. Lochs Morar, Ness, and Uanagan.
„ *acuminata*, Ehr. Lochs Morar, Tay, Ness, and Chon.
Metopidia triptera, Ehr. Lochs Morar and Ness.
„ *oxysternum*, Gosse. Loch Ness.
Colurus bicuspidatus, Ehr. Lochs Ness, Tay, and Uanagan.
„ *leptus*, Gosse. Lochs Earn and Ness.
„ *obtusus*, Gosse. Lochs Ness and St Mary's.
„ *tesselatus*, Glascott. Lochs Ness and Morar.

Family Pterodinadæ.

Pterodina reflexa, Gosse. Lochs Ness and Kinder.
„ *patina*, Ehr. Loch Duntelchaig.
, *truncata*, Gosse. Loch Ness.
Pterodina cæca, Parsons. On *Asellus*, Loch Ness.
„ *elliptica*, Ehr. Loch Ness.

Family Brachionadæ.

Brachionus pala, Ehr. Lochs Duddingston, Soulseat, Spynie, Lindores.
Noteus quadricornis, Ehr. Loch Fithie.

Family Anuræadæ.

Anuræa cochlearis, Gosse. Universal.
„ *aculeata*, Ehr. Loch Clickhamin.
var. *valga* (Ehr.). Lochs Spynie, Lindores, Herba, Dochard, Harelaw, Balnagown.
var. *serrulata* (Ehr.). Lochs Rannoch, Duntelchaig.
var. *brevispina* (Gosse). Lochs Derclach and Grennoch.
Anuræa hypelasma, Gosse. Lochs in Orkney.
Notholca longispina, Kell. Universal.
„ *foliacea*, Ehr. Lochs Rannoch, Earn, Treig, Awe, Ness, Knockie, Dochard, and Duntelchaig.
„ *striata*, Ehr. Lochs Ness, Iubhair, and Carlingwark.
Eretmia cubeutes, Gosse (?). Lochs Ness and Huna.

Family Plœsomadæ.

Plœsoma truncatum (?) Levander (29). Frequent.
,, *hudsoni*, Imhof. Frequent in N. Uist.
Plœsoma triacanthum (?) Bergendal (3). Lochs Oich and Uanagan.

Family Gastropodidæ.

Gastropus stylifer, Imhof (23). Common, noted in about 70 lochs.

Family Anapodidæ.

Anapus testudo, Lauterborn (28). Lochs Ness, Huna, and Uanagan.

Notes on some of the Species, and Descriptions of New Species.

Melicertadæ.

Melicerta.—Empty houses of species of this genus were found adhering to plants in Lochs Ness and Ruthven, but no living example was seen.

Pseudœcistes rotifer, Stenroos? (Plate V. fig. 18) (48), a gigantic free-swimming Rhizotan found in the shallow water of Inchnacardoch Bay, Loch Ness, is doubtfully referred to this species by Rousselet, who has only seen my rough sketch of it. It has much resemblance to *Œcistes velatus*, Gosse, but is much larger, and has the eyes quite differently situated.

Mr Rousselet informs me that Dr Collins figured and described a form having the eyes near the edge of the corona, and has himself collected such an animal in Dr Collins's favourite pool near Sandhurst. He adds that the eyes are seated on an elevated cushion, a feature shown in my sketch. Our animals were larger than any which Stenroos measured. Total length, 925 μ (Stenroos, 750 μ); length of trunk, 450 μ (Stenroos, 280 μ); diameter of corona, 295 μ (Stenroos, 220 μ). Our measurements were made from free examples, Stenroos's from sessile individuals, and the trunk is therefore more extended and narrower relatively in ours; the measurement of the corona is less in excess of his.

My drawing may be taken as a faithful representation of the general form and proportions, and of the viscera as far as shown. The details of the head were less successfully observed, and I failed to make out the correct orientation of the parts. For these, Stenroos's figure (48) may be consulted. The antennæ were not detected.

Stenroos figures the eyes within the corona; my drawing shows them outside the principal wreath. As Stenroos expressly says that the eyes are deep-seated, the difference may be optical, and due to the point of view. Rousselet says the eyes are on the ventral side.

A very powerful, rapid swimmer, as it rushes across the field with the immense hyaline corona widely expanded, it is one of the most magnificent of Rotifers.

Bdelloida.

Structure.—The details of structure given in a previous paper (39) may be here supplemented from later observations.

Rostral processes.—The rostrum of Bdelloids bears generally, and perhaps invariably, at least four different kinds of processes—the *lamellæ*, the *brush* of cilia, *straight setæ* radiating from the tip close under the lamellæ, and some thicker *tactile setæ* which arise singly or in pairs from about the centre of the base of each lamella.

Most authors only mention the lamellæ and cilia, without discriminating the various kinds of cilia or setæ. Janson (24) states that towards the ventral side the cilia are elongated into 'Tastcilien'; Bryce (7) distinguishes between tactile and motile cilia, without entering into details; Weber (52) only mentions the tuft of cilia, but he figures in *Rotifer vulgaris* two kinds of cilia—at each side a pencil of much longer cilia which probably correspond to the *tactile setæ*. Zacharias most clearly discriminates (55) the crown or tuft of cilia and the two long 'Tasthaare.' The straight radiating setæ I do not find anywhere distinctly referred to. Most figures only show one kind of cilia, which may be the tuft or brush, but in many cases probably indicate the radiating setæ.

Rostral lamellæ.—There is a consensus of opinion among authors, including such excellent observers as Zelinka, Janson, Weber, and Bryce, that the rostral lamellæ are two distinct plates, which in those species where they appear to form a single two-lobed hood are really overlapping at the bases. In deference to these authorities I refer to them as lamellæ, although in many cases they seem to me to form a single organ. In microscopical matters it is especially necessary to avoid the bias of authority, and to describe things as they appear to us, as Zacharias pleads (55) when giving an unorthodox interpretation of the vibratile tags. I have never detected this overlapping of the lamellæ. In many species—*Callidina russeola*, *C. tetraodon*, and *C. plicata* for common examples—the lamellæ appear quite distinct and far apart. In most species studied by me they seem to form a single, more or less distinctly two-lobed hood. The meeting-point of the two lobes generally forms a prominent beak, pointing forwards. In the viviparous Philodinadæ (*P. macrostyla*, etc., and the genus *Rotifer*), the appearance gives some support to a suggestion made by Mr Bryce in a letter, that they are adnate (see Plate V. fig. 21).

In a great many instances, when the lamellæ are most fully extended, the two-lobed character disappears, and the organ appears as a simple hood, like that of *Metopidia*, *Stephanops*, or *Diglena*, merely curved forward at the tip (Plate II. fig. 8*g*).

The *brush*, or *tuft* or *crown* of cilia.—Most conspicuous of the rostral cilia is usually the tuft. These cover most of the surface of the evertile tip, and are usually gathered together into a compact brush, which possesses an automatic motion similar to that of the wreaths, but less regular as to direction. By means of them many species can glide forward rapidly, thus supplementing the Bdelloid step. They probably also assist the wreaths, as they are often in active motion when the animal is feeding,

perhaps giving direction to the weak currents setting towards the discs. Sometimes a few of the cilia act alone in a less automatic fashion.

The *straight setæ* have not been referred to by any writer with whom I am acquainted. They (see figs. 2*a*, 2*b*, and 3) are generally present in the central group of the genus *Philodina*, and they have been seen in many *Callidinæ*. They may be always present, but, if shorter than the lamellæ, would be difficult to see. They vary greatly in length, are conspicuous in *P. rugosa* and *P. acuticornis* (fig. 3), and reach the maximum yet observed in *P. brevipes* (figs. 2*a*, 2*b*). Their function may be supposed to be the same as that of other motionless rigid setæ, such as the whiskers of the cat.

The *tactile setæ* are somewhat flagelliform, tapering and undulate, but thicker than true flagellæ. They vary much in length and thickness, but are always considerably thicker than any other setæ on the rostrum. In some species they are unmistakably paired; in others where they are very small it is uncertain whether there are one or two on each side of the tip. Their motions sometimes appear automatic, but often they seem to be under intelligent control. In *P. macrostyla* and the related species, *P. aculeata* and *P. spinosa*, these setæ are the longest I have seen. In the act of extending the rostrum, these species often put out first the four long setæ as feelers. They undulate slowly, are separated and brought together again, and the animal appears to be feeling if it is safe to come out (fig. 21). These setæ have been seen in the above-mentioned and many other *Philodinæ*, in all species of *Rotifer* where they have been looked for, and in a number of *Callidinæ*. ZACHARIAS (55) figures them of great length, on the ventral side of the brush in *Rotifer vulgaris*; but they appear to be dorsal in the species I have examined.

Central setæ on discs.—The central seta on the disc of a Philodine, or it may be a pencil of very fine setæ, is a familiar structure. The seta usually rises from a papilla, which may be of large size. Central setæ were known in several *Callidinæ*, but they were supposed to be absent from most species of this genus, from all species of the genus *Rotifer*, and from one section of *Philodina*.

Recently I found that *Rotifer socialis* (*Callidina socialis*, KELLICOTT, which I transfer to the genus *Rotifer*) had in place of the central seta a cluster of short motile cilia (fig. 15*a*). This led me to expect that some modification of the central seta would be found in other species of *Rotifer*, and perhaps throughout the whole of the family Philodinadæ. On *R. tardus* there has been detected a single curved seta, of extreme tenuity, apparently motionless (fig. 22). A large variety of *R. vulgaris*, found in Loch Tay, had shorter setæ which were in active motion. Two curved lines marked the limits of motion in each direction, as we often see in *Vorticella*, etc. (fig. 23). *R. citrinus* has similar setæ.

The papilla from which the central seta springs is generally small; it may be entirely absent; or the greater part of the summit of the disc may be produced into a conical base for the seta (*P. alpium*, etc.).

A peculiar papilla has been seen as yet only in two species, *Philodina laticeps* and *Callidina magna* (fig. 6). It is a large, elevated, gently tapering, conical peg, truncate or slightly expanded at the tip, and bearing there a number of very short motile cilia.

Perforated spurs.—It has been asserted by various authors (ZELINKA, JANSON, etc.) that the spurs of certain species (*Callidina russeola*, *C. vorax*, *C. parasitica*, etc.) are perforate at the tips, and that ducts convey mucus from the foot-glands to these pores. I have never been able to satisfy myself that any species which I have studied had habitually mucus ducts to the perforate spurs. In two instances, however, have I seen mucus exuding from the tips of the spurs. One example of *Callidina scarlatina* and one of *Philodina acuticornis* (figs. 5, 9*d*) had the mucus forming a thick deposit round the tip of each spur, and gradually tapering to a drawn-out thread, which made the spurs appear longer than they really were. The deposit round the two spurs was too symmetrical to be attributed to accidental contact with the mucus of the toes.

MICRODINADÆ.

Systematic position.—The relation of the various families of Rotifera to one another is very puzzling. One group of characters would lead us to associate certain families; other groups would lead to different combinations. The discovery of aberrant animals generally assists in the elucidation of affinities, though they often destroy the symmetry of our classifications. Does *Microdina* help us to understand the affinities of the Bdelloids?

The jaws, which I suggested (39) were a kind of link between the Bdelloida and the Melicertadæ, really lead almost as directly to many families of Ploïma, and even to the Scirtopoda.

The Microdinadæ and Seisonidæ may be profitably compared. Both are true Digonata, though this is not brought out in my original figures of *Microdina* (39). The relationship of the Bdelloids and Seisonidæ is perhaps best shown in LUND's classification (31), where he makes them orders of Digonata; but *Microdina* somewhat diminishes the distance between them. *Seison* approaches the Bdelloids not only in the Digonate character, but in the telescopic neck and foot, while the two tufts of setæ recall the wheels of the Bdelloid corona. *Microdina* approaches the Seisonidæ in the shortened gullet, reduced corona (*Paraseison*), and jaws departing from the ramate type. *Seison* has jaws quite remote from the ramate, and more resembling some of the Notommatadæ, and most conspicuously differs from *Microdina* in the union of gullet and œsophagus.

Seison is highly specialised, in adaptation to a peculiar situation and mode of life. *Microdina* does not occupy a peculiar situation; it leads a free life, in company with many other Bdelloids, on mosses and other aquatic plants. It merely gets its living in another manner, and is modified accordingly. The lack of discs and the very strong

toes seem to me adaptive characters. As it feeds by biting, it does not need discs; and as it has not discs, and therefore cannot swim, it would be under a disadvantage without powerful toes.

The close correspondence to the Philodinoid type of structure in almost all but the corona and jaws, especially in the rostrum and foot, suggests that the peculiarities of *Microdina* are due to retrogression from *Philodina*. On the other hand, the transition from a fully developed Philodine to *Microdina* is difficult to imagine, because the short gullet and protrusible jaws must be completely acquired before they would be serviceable.

Since the jaws approximate to the central type of the whole class (see GOSSE on the manducatory organs (17)), and the short gullet and protrusible jaws are also frequent throughout the Ploïma, there is some ground for supposing that the Philodinoid corona never has been developed, and that the mouth and jaws are more primitive characters surviving from a common Bdelloid ancestry, from which the Microdinadæ are an earlier branch than the Adinetadæ.

Such conclusions are little more than conjectures, and the discovery of other links may prove that the affinities are quite other than I have supposed.

Microdina paradoxa, MURRAY.* (Plate IV. fig. 17.)

Since the species was described (39), it has been found frequently in lochs and streams. It has thus been possible to learn more about its structure and habits.

The characteristic red mass in the head has been definitely ascertained to surround the œsophagus. Small examples, which I take to be young, lack this red mass, and are colourless throughout.

The very short gullet was early pointed out as an important character by Mr BRYCE (to whom I am greatly indebted for assistance in elucidating the structure of this anomalous animal). The meaning of the short gullet is now understood. The jaws can be completely protruded, as is done by many predatory Notommatadæ, etc. The jaws are not merely snapped and withdrawn. It has been seen to seize a filament of *Spirogyra*, and leisurely chew it for a long time, the jaws all the while half out of the mouth.

PHILODINADÆ.

The three genera of this family which occur in the lochs are redefined to permit of a more natural arrangement of the numerous species. The eye-spot is given up as a generic character. The character of the toes is the most important feature used in the classification; the mode of reproduction is made use of, for want of anything better. Whatever objection there may be to using the mode of reproduction, unquestionably it characterises natural groups in the Bdelloids.

* Recently collected by Prof. FOREL in the Lake of Geneva, the first record, to my knowledge, outside of Scotland.

Philodina.—Toes four. There may or may not be eye-spots; when present, they are cervical. The genus is divided into three sections, denoted by the letters A, B, C. The first two are only for convenience; the third is natural (except *P. laticornis*), and should perhaps form a separate genus.

A. Oviparous, eyes cervical.
B. Oviparous, eyes absent.
C. Viviparous, eyes present or absent.

P. brevipes, MURRAY. (Plate I. figs. 2*a* to 2*c*.)

Though occasionally locally abundant, the species is uncertain in its occurrence. Its abundance in Loch Morar in 1903–4 enabled me to study it more fully than when the animal was first described (39), and better drawings were obtained, which are here reproduced.

The straight setæ on the rostrum are of extraordinary length, projecting at each side considerably beyond the sides of the head. There are thick tactile setæ under each lamella (fig. 2*b*); it is uncertain whether there is a pair at each side, as there is in *P. macrostyla.*

Seven pairs of vibratile tags were seen—at each side two in the head, on each branch of the forked canal, one pair in the first cervical segment, and four pairs in the central segments. They are set at equal distances apart, but there is a gap in the series, or a wider interval, at the level of the mastax, or between the third and fourth tag at each side, counting from the front. This hiatus appeared in several individuals studied, so I hardly think the tags (which are conspicuous) have been overlooked.

The foot is three-jointed, but there is often an appearance of four joints. In fig. 2*c* I show how this is brought about. Each telescopic segment of the foot of a Bdelloid consists of a somewhat firm cylinder. These are joined together by soft, flexible skin, which renders the telescoping possible. Where the soft skin joins the firmer cylinder there is often a little elevated ridge, more marked than usual in the present species. In the fullest extension of the foot this soft skin, with its limiting ridge, appears like an extra joint.

In Loch Morar, in 1903, all the examples found had a hair-like growth on the head. Mr BRYCE considers this hair as fungoid, and attributes to such a growth the *P. hirsuta* of various authors. It is difficult to understand the symmetry of the hair, and its confinement to the head. In *P. laticeps*, similarly affected, the growth was confined to the trunk.

Differing from *P. citrina* in many points, careful study is necessary to discriminate the two species. Less massive than *P. citrina*, *P. brevipes* is also of quick, restless habits, very different from the elephantine deliberation of its relative. The marked characters of rostrum and foot are often difficult to observe. The number of teeth is not a safe character, as *P. brevipes* has the usual $2+1/1+2$, with the third tooth not infrequently as thick as the others.

P. flaviceps, n. sp., Bryce. (Plate I. figs. 1*a* to 1*f*.)

See description further on.

One of the commonest Bdelloids in Scotland, in lochs, streams, bogs, etc. Too common in lochs to call for details of distribution. Ubiquitous though it is, it yet evinces a preference for pure waters.*

The spurs are somewhat variable. In fig. 1*f* I have shown the typical short, blunt spurs; in fig. 1*d*, a longer, straighter pair; in fig. 1*e*, a peculiar form often found in animals otherwise typical; they are placed close together, incurved, acute.

An abnormal example, with flame-shaped 'ligule' between the discs, was found in Loch Ness.

P. rugosa, Bryce (9).

Extremely variable; the type has dental formula 3/3, and red eyes. A variety in Loch Morar had no eyes, teeth 2/2, and a boss on the first foot-segment, as in many *Callidinæ*.

P. acuticornis, Murray (37). (Figs. 3 and 9*a* to 9*d*.)

Occasionally found in lakes, though more at home in bogs and ponds. The original figure being somewhat poor, better drawings since obtained are here given (figs. 9*a*, 9*b*). In dorsal view a graceful animal, the light corona, thin neck, and slender foot tapering to the narrow, acute spurs all impart an appearance of lightness. This appearance is deceptive. In lateral view (fig. 9*b*) it is seen that it has none of the dorso-ventral flattening which is usual in Bdelloids. The central part of the trunk is very deep from front to back—in fact, quite barrel-shaped. This bulk of paunch is necessitated by the very voluminous stomach. The head and foot are really light. In keeping with its heavy trunk, the gait is slow and deliberate. The transverse ventral folds between the segments are distinct and equidistant, as the animal takes the forward step.

P. laticeps, Murray (39).

Though discovered on insect larvæ, this is now known to be the commonest parasite on *Gammarus* in Scotland. This led to a suspicion that it might be identical with Giglioli's *Callidina parasitica*, which he found so common on *Gammarus*. Giglioli (15) says the corona is small, and figures it as extremely small. It is true that the measurement he gives for a small example makes it very large, but there are contradictions in his other measurements; so we are justified in concluding that a deliberate statement, and still more deliberate drawing, are conclusive.

The most obvious distinctive character of *P. laticeps* is the great spreading corona. The pointed end of the last foot-joint of *C. parasitica* is unlike anything in *P. laticeps*. The antenna (calcar) is said to be large and well developed. These terms are relative,

* While these notes are in press, *P. flaviceps* has been found in abundance among moss collected by Prof. Forel in the Lake of Geneva.

but GIGLIOLI's figure shows it prominent at the side, which could hardly be the case with the short, turgid antenna of *P. laticeps*.

GIGLIOLI makes some remarkable statements, which may well seem erroneous, as when he describes a ventral proboscis, at the end of which is the mouth, making no mention of the usual dorsal rostrum—this proboscis, with the mouth, being retracted when the animal is feeding; still, his account is so circumstantial that we must expect *C. parasitica* to have some correspondence with his detailed descriptions and figures. If it were *P. laticeps* which he studied, then it could never be identified from his description, and would have to stand as insufficiently described.

There is no reason to suppose this. *Gammarus* has many other parasites, and new ones are still coming to light. One, *P. hamata*, is here described; another is presently under study. The commonest parasite in one locality may not be the commonest in another. *P. commensalis*, one of those found near London, has never appeared on any *Gammarus* collected by us.*

P. hamata, n. sp. (Plate II. figs. 7*a* to 7*i*.)

Specific characters.—Large, slender; trunk narrow, lacking conspicuous enlargement of central portion; corona very large, much exceeding collar; pedicels long; discs large, oval, thin, saucer-like; antenna long, equalling diameter of neck; rostrum narrow; no eyes; jaws small, teeth 2/2; foot long, of five joints, scarcely tapering from anus to spurs; spurs large, very broad and meeting at base, quickly tapering to acute points, strongly outcurved, so that points on line with base, very strongly decurved; toes four, basal pair small, enclosed in a common basal sheath, close to spurs; ventral pair long, divergent, three-jointed; a fold of skin round bases of spurs on dorsal side. Oviparous.

On *Fontinalis* growing in the river Lochay, near to its junction with the river Dochart, in abundance, November 1905.

When the *Fontinalis* was washed, a great many *Gammarus* were found, and the Rotifer was also abundant, but it was not seen on the *Gammarus*. The appearance of the animal has many points of correspondence with the *Gammarus* and *Asellus* parasites. These are for the most part of large size, with lanky, narrow bodies, long foot, powerful spurs, large corona, and no eyes. In all these respects *P. hamata* looks like a parasite. In a second washing of *Fontinalis* from the same place only a few *Gammari* appeared, and few of the Rotifers. On a third occasion no *Gammarus* was found, and only one *Philodina*.

P. hamata has a close general resemblance to *P. laticeps*. The discs are of the same form, like thin elliptical saucers, and almost as large. They have not, however, the peculiar process characteristic of that species. Other points of difference are the longer and narrower rostrum and antenna, more numerous foot-joints, different form of spurs, with no interstice, and ridge of skin where the spurs join the segment.

* Mr BRYCE thinks this has never been found on *Gammarus* anywhere.

The spurs are very strongly curved. In lateral view they look like a drag-anchor; in dorsal view the points are often further forward than the base. They are very slightly movable, and these positions are maintained. The toes are of quite unusual structure. Close under the spurs there projects from the back of the terminal foot-segment a short cylindrical joint; from this issue two short, curved, pointed toes looking like a second pair of spurs; the segment then forks and bears the very large terminal toes. As was the case with the related *P. laticornis* (39), the toes are seldom retracted, but remain extended after the new grip has been taken.

The species has now been definitely ascertained to be parasitic on *Gammarus*, both in Loch Tay and in St Mary's Loch.

It has been sufficiently distinguished from *P. laticeps* above. The remarks made under *P. laticeps* about *Callidina parasitica*, GIGLIOLI, serve to distinguish *P. hamata* also from that species. The lack of eyes, besides other characters, separates it from *P. laticornis* and *P. commensalis*. No other species known to me comes near enough to need detailed comparison.

Callidina.—Oviparous; toes three, or united to form a sucker. This genus also is divided into three sections, indicated by the letters A, B, C. The first is a very natural group, the other two are not so certainly distinct; the symbiotic foot may have been independently acquired by diverse animals, and ZELINKA's various symbiotic species do not seem to be particularly closely related otherwise.

A. Food moulded into pellets.
B. Toes three, distinct, no pellets.
C. Toes united to form a sucker.

These subdivisions are rendered necessary by the diverse structure of the numerous species. Group A, the pellet-makers, is one of the largest natural groups within the order, many species being still undescribed.

Although all conform to a uniform type of structure, there is great diversity of external form, the most aberrant being probably *C. cornigera*, *C. ræperi*, and *C. hexodonta*.

These last two are the only species of the genus *Callidina*, as here defined, which possess eyes. As these are placed as in the genera *Rotifer* and *Philodina* respectively, this may be an indication that the group of the pellet-makers is of more than generic value.

In Mr BRYCE's projected revision of the classification of the Bdelloids, I understand that the three subdivisions of the genus *Callidina* here adopted will be among the groups elevated to generic rank.

C. hexodonta (BERGENDAL) (2). (Plate III. fig. 13.)

Mr BRYCE has suggested, very plausibly, that this may be *Philodina collaris* of EHRENBERG. As there is some doubt about it, while it is pretty certainly the *Philodina*

hexodonta of BERGENDAL, I retain the latter's specific name in the meantime. Very common in bog-pools, casual in lakes; rarely seen to feed. On one occasion when many were found readily feeding, some details of the head were got (fig. 13). The corona is fairly large for a pellet-maker, rather less than the collar but greater than the neck in diameter. The discs stand some distance apart, and the space between is occupied by a conical ligule. The ligule in Bdelloids is of very uncertain stability, often appearing as a sport in species where no ligule is normally present, and is therefore an unsafe specific character. All the examples of *C. hexodonta* examined possessed one. The very long antenna is kept out when feeding.

C. pusilla, BRYCE (6). (Plate III. figs. 12*a* to 12*c*.)

The type of this species, having a meagre case, has rarely occurred in our collections. The var. *textrix* is frequent. This has a very bulky case, composed of many concentric layers of gelatinous matter. I find two forms which make such cases, and consider them as specifically distinct. One, with a very prominent spout-like lower lip, is here figured (figs. 12*a* to 12*c*). The other, in which the lower lip is not at all prominent, has not been fully studied. The form figured has very prominent rostral lamellæ, a short, thick antenna with very long setæ, and the upper lip terminating in the median line in a projecting ligule-like process. It readily leaves its case and wanders for some time unprotected.

C. longiceps, n. sp. (Plate III. figs. 11*a* to 11*c*).

Specific characters.—Small, with oval trunk, longitudinally plicate; neck narrow, of moderate length; head much elongated; corona slightly wider than the collar, upper lip very extensive; basal segment of rostrum greatly laterally compressed, terminal segment fairly long, terminating when fully extended in a very low cone (the everted tip) covered with short cilia and with no trace of rostral lamellæ. Antenna equal to half the diameter of the neck. Teeth 5/5. Food moulded into pellets. Flame-cells spindle-shaped; three pairs seen. Inhabits a firm, membranous, dirty-yellow case, to which much extraneous matter adheres.

Many Bdelloids inhabit houses of some sort for protection. In *Rotifer macroceros* and some other species the house is little more than an untidy accumulation of débris, collected by the discs in the process of feeding. Others secrete firm membranous cases from the skin of the trunk, and these have a definite form determined by that of the body. Others, again, adopt the cast-off shells of other animals, or joints of the limbs of arthropods, or even vegetable structures. *Callidina annulata*, *C. scarlatina*, and the other so-called symbiotic species adopt a ready-made shelter. Cases of definite form are most commonly secreted by *Callidinæ* of the pellet-making section—among others, by *C. eremita*, *C. angusticollis*, and *C. pusilla*, var. *textrix*. To which class the present

animal belongs is not quite certain. The case does not fit the body very closely, yet does not resemble any other definite organic structure known to me.

Total length when feeding, 277 to 312 μ; length of head from corona to first neck-segment, 77 μ; diameter of corona, 40 μ; length of jaws, 33 μ; of vibratile tags, 12μ. Pellets variable in size, some elongate, and up to 18 μ long. The pellets, after voiding, were cleared out of the case in the same deliberate way I have described (39) in the case of *C. angusticollis*. The rump is slightly marked off from the central trunk, but under the strongest pressure no trace of foot could be seen. I do not doubt that it exists, however, as there is often difficulty in getting a hermit-species to display the foot. The five teeth are unusually strong for a pellet-maker, and there are besides the usual striæ. The peculiar form of the extensive area (upper lip) between the rostrum and the pedicels will be better understood, and the mode in which it joins with the rostral base better seen, from the figures than from any description.

In the half-extended rostrum two rounded lobes suggest the lamellæ; but when the tip is most fully everted there is no trace of lamellæ, though they were very carefully looked for. No processes were seen on the low conical tip except very fine setæ of uniform length, which covered it all over. No central setæ were seen on the discs.

Habitat.—On aquatic mosses from the islands in Loch Morar, 5th March 1905.

C. aspera, Bryce (5). (Plate IV. figs. 16*a* to 16*c*.)

Its abundance in Loch Ness and district enabled me to study some points in the structure of this interesting species which I have not seen previously noted. The food is moulded into pellets—a character readily overlooked, owing to the thick papillose skin. The large discs are close together, and strongly inclined forward. The apparent motion of the cilia passes uninterruptedly round both discs, as though they were one, as is also seen in *C. annulatus*, *Œcistes*, etc. The upper lip terminates in a median conical process, which looks like a 'ligule,' though really of another nature. A similar process is seen in *C. pusilla* (fig. 12*b*).

C. crenata, Murray. (Plate I. fig. 4.)

When described (39), the animal had not been seen feeding. This has now been done, and the corona is figured. The head is relatively very small, and the corona less than the collar.

C. habita, Bryce (7).

Apparently a variable animal, but there is a suspicion that several similar species have been confused together. A remarkable variety, probably of specific rank, is described below.

Lochs Ness, Morar, Treig, Gelly (Evans).

Var. *bullata*, n. var. (Plate III. figs. 10*a* to 10*d*.)

Distinctive characters.—Less robust than the type, head and foot more elongate, colour yellowish. First joint of foot with eight prominences, in three rows: first row, nearest base, of four equal hemispherical processes, two lateral, two dorsal; second row, of two lateral processes, like those of the first row, and one median dorsal, transversely elongate, as though formed by the junction of two hemispherical processes; third, a single very prominent median process.

The very ornate foot is the most important character of the variety, but the narrower form, longer extremities, and yellowish colour all further distinguish it from the type. A few examples were sent to Mr BRYCE, who succeeded in finding them, and after some study suggested that the form belonged to *C. habita*. In deference to his opinion, I subordinate it to that species as a variety.

Among submerged moss on rocks at the margin of Loch Treig, December 1904, abundant. Recently found also in India.

Rotifer.—Viviparous, toes three, eyes present or absent. When eyes are present they are in the rostrum. All the species in this list possess eyes, except *R. longirostris* (JANSON) and *R. socialis* (KELLICOTT).

R. neptunius, MILNE (35).

This is closely related to *R. trisecatus* (51), which it nearly equals in length, but is narrower. I can only see two joints in the long spurs; in *R. trisecatus* there are three. The ventral toes are of extraordinary length, when fully extended even exceeding the spurs, but appear to be only two-jointed. The median dorsal toe appears shorter; if it be as long as the others, it is habitually less extended. The teeth on the jaws are of only moderate thickness.

R. trisecatus, WEBER (51). (Plate V. figs. 20*a* to 20*c*.)

This gigantic Bdelloid was only once seen in a loch, but is known in ponds (38, 47). The foot is short for the genus, but of the usual five segments. The very large spurs are distinctly three-jointed (fig. 20*c*). I have never seen it feeding, so as to observe the characters of the corona. A very good distinctive mark of the species is offered by the teeth (fig. 20*a*), which are of very unusual breadth. These are better shown in WEBER'S original figure (51, Plate XXX.) than in his later work (52, Plate 14).

R. socialis (KELLICOTT). (Plate IV. figs. 15*a* to 15*e*.)

The commonest of the parasites on *Asellus*. An extremely long animal, and ungainly when creeping, it assumes the form of an elegant vase when feeding. The very

long foot has one segment more than is usual in the genus. The large figure (15*a*) on Plate IV. shows the foot partly retracted; the smaller figure (15*b*) shows the true proportions. The corona is of the form usual in the genus. The discs bear each a central tuft of motile cilia, corresponding to the central setæ of *Philodina*, etc. The collar is more worthy of the name than usual, consisting of a long pendant flap, very broad in the lateral part. Intestine pear-shaped. Reproduction viviparous. Loch Ness and the Caledonian Canal.

Adinetadæ.

A. tuberculosa, Janson (24). (Plate IV. fig. 14.)

This species has been found among hepatics at the margins of one or two lochs, and in other situations. The most distinctive character of the species is the series of coarse papillæ which cover part of the body.

All the Scottish examples differ from Janson's description in one important particular. Janson says that the tubercles cover the whole body, with the exception of the last foot-segment. All the examples I have seen have no tubercles on the central segments of the trunk. On the adjacent neck-segment and preanal the papillæ are largest, and diminish in size forwards and backwards from these segments, but remain large in several rows in the middle of the head. Their absence from the central segments is the more remarkable, as, in most species possessing a similar armature, this is confined to these very segments, or is strongest there and diminishes or disappears on the neck and foot.

The spurs also differ from those figured by Janson, which are simply tapering, acuminate and acute. In our specimens they are enlarged from the base upwards for about two-thirds of their length, then shortly acuminate.

Margins of Lochs Ness and Earn.

Notommatadæ.

Albertia intrusor, Gosse. (Plate V. figs. 24*a* to 24*d*.)

In every example of *Stylaria lacustris* which I have examined under pressure, one or more parasites of the genus *Albertia* were invariably present. The species comes so near *A. intrusor*, Gosse—although Gosse's figure gives no idea of the great posterior enlargement—that I identify my animal with that species.

In situ in the gut of the worm they were readily detected by their motions, alternately extending and contracting. When set free by the death of the host their behaviour was remarkable. They crept along in Bdelloid fashion, although no hold appeared to be taken by the toes. The head-grip was loosened, the posterior part of the body apparently

retaining its position by its superior weight till a new grip was taken by the mouth. The remarkable feature was that they walked backward, and at each step the anal region was greatly expanded, being then by far the widest part of the body, perhaps twice the diameter of the middle of the trunk. In this action the short foot became quite lateral. The individuals behaving in this way carried eggs, and I interpret the action as an attempt to lay the eggs as the fear of death came upon them after the death of the host. When first the species was observed, this action was going on; the small jaws had not been seen, and the mode of creeping gave the impression that the broad end was anterior, and the expanded anus a great sucker with which the animal was seeking for a fresh hold. The true relation of parts soon became apparent.

Proales daphnicola (Thompson) (50). (Plate VI., figs. 26*a* to 26*e*.)

Mr Rousselet identifies as this species an animal of which I sent him a drawing, although there are some little discrepancies.

If it is this species, the situation in which it was found is remarkable. It was dredged at a depth of 500 feet in the middle of Loch Ness, and it was parasitic, not upon a Daphnid, but upon an oligochæte worm. When examined, the worm was moribund: the Rotifers, though all living when first seen, soon died, and the studies obtained were not so complete as could be desired. The species of worm was not ascertained. It was either a different species from the others taken in the same dredging, or it was in a pathological condition, as it adhered to the glass when placed upon it, which the others did not.

Five individual Rotifers were adhering to the worm, near the extremity. All were in the same position, the very broad head applied to the skin, and the feet all pointing backwards.

This is the greatest depth at which we have obtained a Rotifer, although in Loch Ness many go down to 300 feet.

Pleurotrocha parasitica, Jennings (26).

From a very incomplete drawing, Mr Rousselet suggested this identification. On comparing Jennings' figures, I am satisfied that this is the animal found, adhering to the skin of an Oligochæte, in Loch Ness.

Furcularia longiseta, Ehr., var. *æqualis*, Ehr.

A variety with equal toes was frequent in Loch Morar in 1903. The animal was both smaller and more slender than the type, and the equal toes were almost quite symmetrical.

F. quadrangularis, (GLASCOTT) (16).

In spite of some little discrepancies, Miss GLASCOTT's rough drawing of *Notops quadrangularis* faithfully represents a little animal which is not infrequent in lochs, though never abundant. The patches of brown globules render the identification almost certain. The trunk is very broad, oblong, of firm texture, and maintains its shape. In the Scotch examples the patches of globules have a slightly different arrangement from that shown in Miss GLASCOTT's figure. The two shoulder patches are the same; there is only one posterior patch, which is median and dorsal; there is a less-defined median dorsal patch between the shoulder patches. The eye is smaller and nearer the front; the toes are rather shorter. The foot is telescopic and elbowed, as in *F. reinhardti*, but it performs none of the contortions of that violent species. This is a very unobtrusive, quiet little beast, which goes slowly about, feeding, scarcely altering its form or the position of the foot. From the position of the eyes, the characters of the foot and of the jaws, as far as seen, it seems to me to be a *Furcularia*, and not a *Notops*.

F. reinhardti, EHR. (? = *Notommata theodora*, GOSSE).

Of very common occurrence in Scottish lochs is a narrow, long-footed animal of the genus *Furcularia*. Whether there is only one species of this description is not certain; sometimes it is of moderate size and quiet habits, sometimes very large and extremely active, the general form in both cases the same, and the animals not separable without closer study than we have been able to give. GOSSE's description of *Notommata theodora*, its form, glassy transparency, and the mode of moving the immensely long foot, apply perfectly to the larger form. Great numbers of the lesser form are often found, in plankton collections, dead or dying, with a filament of some sort, algoid or fungoid, apparently choking them. The foot is habitually bent downward, as well as from side to side.

DINOCHARIDÆ.

Dinocharis tetractis, EHR.

This species varies greatly in relative length and breadth. The extreme in one direction is a form frequent in bogs. The trunk is very large, very broad, and the foot relatively small. This occurs in lochs, but is rare. Lacustrine specimens are generally much narrower, the foot and the toes relatively longer, in extreme forms approaching the next species, though always distinguishable by the proportions of the foot-joints. I have already noted, in treating of the abyssal region, the reduction of the foot-spurs in abyssal examples.

D. similis, STENROOS (48).

This species, distinguished by the great elongation of the second foot-joint, was of rare occurrence in Loch Ness, and has not yet been seen in any other loch.

Stephanops tenellus, BRYCE. (Plate V. figs. 19*a*, 19*b*.)

Discovered by BRYCE in moss from Spitzbergen (8). The extreme activity of the animal baffled its discoverer in his efforts to secure a portrait. At a later date, when it was found in Loch Ness, I was more fortunate, and subsequently, with the aid of narcotics, obtained the drawings here presented.

It is very closely related to *S. stylatus*, MILNE (35), of which it is almost an exact miniature. The most important points of difference are, the smaller size, narrower form, narrower and longer jaws, and shorter toes. As Mr BRYCE pointed out, under low powers the viscera give the apparent outline of the central parts of the trunk, the hyaline lorica being invisible, and the animal seems more slender than it really is. Both head and lorica are, however, relatively narrower than in *S. stylatus*. In dorsal view the toes are about $\frac{1}{12}$ of the total length, those of *S. stylatus* about $\frac{1}{7}$. Owing to the strong decurvature of the toes of both species, their actual length forms a greater proportion of the whole than these figures indicate.

Length, about $\frac{1}{226}$ inch (110 μ). This is larger than BRYCE states ($\frac{1}{300}$ inch), but such a lively animal is not easy to measure. After death accurate measurements cannot be made, as under pressure dead examples elongate in a remarkable degree. *S. stylatus* is nearly twice as long. Many examples contained a well-developed egg. The pair of very long setæ are directed upwards as well as backwards. The number of forward-pointing setæ is uncertain. The strong motile cilia by means of which the animal runs forward are, both in appearance and mode of action, singularly like the 'legs' of *Euplotes charon* and related Ciliata.

COLURIDÆ.

Colurus tesselatus, GLASCOTT (16). (Plate VI. figs. 27*a*, 27*b*.)

A little facetted *Colurus* found in Loch Morar and Loch Ness belongs, I think, to this species, although it differs greatly in form from Miss GLASCOTT's figures. She shows the lorica, in side view, as triangular, and highest in front; in dorsal view, as greatly expanded at the posterior angles, although broadest in the middle.

The animal, as I know it, agrees with Miss GLASCOTT's description as to the tessellated surface, raised at the sutures. It differs in the following points:—The form is that normal in the genus; in lateral view an evenly rounded back is seen, highest a little in front of the middle, and very little lower at the posterior edge than in front. In dorsal

view it is seen that the sides are flat and parallel in the middle, with sloping portion making about the same angle to the front and back. The posterior sinus is concave, of moderate size, the anterior small. A slight ridge marks the middle of the back. The facets are symmetrically arranged on each side of this; they do not break the median line as shown by Miss GLASCOTT. There are about nine distinct facets on each half of the lorica, and they are in three rows parallel with the median line.

Miss GLASCOTT considers it a rare species, and it is so in Scotland. It has only been found in two lochs in Scotland, Lochs Ness and Morar. Not very abundant when gathered, it increased greatly during a whole winter, in tightly corked bottles.

PLŒSOMADÆ.

The confusion of the synonymy among the species of this family is, I imagine, without parallel among Rotifers. This has now been pretty well sorted out, but while it prevailed it was found difficult to name most of our species, so the distribution in Scotland is not traced.

Plœsoma triacanthum (BERGENDAL) (3). (Plate VI. figs. 28*a*, 28*b*.)

Though I have recorded under this name a three-spined *Plœsoma* found in one or two lochs, there is some doubt as to its being that species. There has since been found in a pond in the same district a smaller animal which agrees more closely with BERGENDAL'S and LEVANDER'S figures. Fig. 28*b* is the animal found in the lochs; fig. 28*a* is the smaller species, probably *P. triacanthum*; both are drawn to the same scale.

ANAPODIDÆ.

Some authors (10, 30), have doubted the specific distinctness of the two alleged species of this genus, and those who admit both, as WEBER (52), agree that they are separated by very minute characters.

Being unable to decide to which species our animal should be assigned, or to find out which of the two names, both of which were bestowed in the same year, has priority, I put it under that which it most resembles.

ANURÆADÆ.

Eretmia cubeutes, GOSSE.

No living *Eretmia* has been seen, but in Loch Ness were found numerous tests, strikingly like Rhizopod shells.* The spines were placed as in *E. cubeutes*, and most of the tests contained the trophi of a Rotifer, in the same definite position.

* Mr ROUSSELET has little doubt these are Rhizopod shells, into which Rotifers have somehow got; but they are quite different from the only Rhizopod (*Euglypha alveolata*), of similar form, known to me.

NOTOMMATA PUMILA, n. sp. By C. F. ROUSSELET, F.R.M.S.

(Plate VI. figs. 25*a* to 25*c*.)

Specific characters.—Body stout, elongated, plump and rounded dorso-posteriorly; the head remarkably small, less than half the width of the body immediately behind it, tubular, and surmounted by a tuft of vibratile cilia, without auricles or other prominences; small clear brain with small cervical eye on the under surface near its posterior extremity. Foot stout and rounded, carrying two small, pointed, slightly recurved toes, deeply shouldered on the dorsal side of their extremity. Size—length, 127 μ ($\frac{1}{200}$ inch); width, 54 μ ($\frac{1}{470}$ inch); toes, 14 μ ($\frac{1}{1800}$ inch).

Habitat.—Amongst moss in Caledonian Canal near Fort-Augustus, Scotland.

I found this species in November 1904, by washing out damp moss kindly sent to me by Mr JAMES MURRAY from the Caledonian Canal; but it appears it had previously been observed in January of the same year by this gentleman, and I could readily recognise it from his sketches.

The peculiar formation of the small tubular head gives the animal a striking aspect, which is only shared by Miss GLASCOTT's *Notommata gigantea*, with which it has indeed considerable resemblance; and if it had not been for the peculiar structure of its toes and its diminutive size, I would have been inclined to refer it to that species.

The integument is white, transparent, soft, and yet with a certain amount of stiffness, so as to always maintain the animal's shape. Posteriorly, a broad triangular fold indicates the beginning of a stout, jointless foot, which carries two short recurved toes, of peculiar and characteristic shape, distinctly and deeply shouldered at the extremity; an enlarged figure of the toes is given in fig. 25*c*.

A clear brain of moderate size carries a small red eye on its under side.

The mastax is of large dimensions for the size of the animal, and contains powerful and complex jaws of forcipate type (fig. 25*b*). The manubria in particular consist of two separate chitinous rods on each side, and joined at their extremities. I do not remember a similar structure in any other Rotifer. The unci are broadened plates, apparently without teeth—at least I was unable to detect any. Above the unci were seen some apparently loose and curved chitinous rodlets, which remained in position after dissolving the soft parts with caustic potash. The rami are small, and their exact shape and structure difficult to observe. In fig. 25*b* I have represented what I was able to make out of the incus; the fulcrum is a narrow and short rod, curving inwards and broadening at its base.

Dorsal and lateral antennæ are present in their usual positions. A large stomach and intestine fill the greater part of the body cavity; the other organs are quite normal and call for no detailed description.

Notommata gigantea, with which I have compared this new species, is vastly larger, reaching 726 μ ($\frac{1}{35}$ inch) in length, according to Miss GLASCOTT, has very small toes, which are not shouldered, and the mastax also is small and apparently

contains jaws of a different type. These differences sufficiently separate the two species.

The figure accompanying this description has been drawn by my friend, Mr F. R. Dixon-Nuttall, with his accustomed skill from my mounted specimen.

Philodina flaviceps, n. sp. By David Bryce.

(Plate I. figs. 1*a* to 1*f*.)

Specific characters.—Of medium size (about 320 μ), and only moderately stout. Skin smooth. Corona rather ample (about 70 μ), about one-fourth more than collar. Rami with 2/2 teeth. Foot of four joints, moderately stout. Spurs, short thick cones (about 6 μ long), held nearly parallel, separated by a concave interstice (3 μ wide). Toes four.

This species was very abundant in washing of *Lemanea* (*Sacheria*) gathered in Loch Vennachar in May 1902 by Mr James Murray, and has occurred later in gatherings from other waters sent to me by him from time to time. Its distinctive features are the shortness and thickness of the spurs, the marked concavity of the interstice, and the rather ample expanse of the corona, whose width equals quite one-fifth of the length of the animal. Moderately grown examples might perhaps at first sight be taken for *P. nemoralis*, but attention to these details will sufficiently establish the identity of this species. Most of the examples seen were noticeable for their clear yellow tint, and especially because the colouring was not confined to the trunk, or central portion of the body, but extended over the neck and head as far as the rostrum. This deviation from the general rule has suggested the specific name.

The antenna was of moderate length, and the mastax and other organs were apparently normal.

Although the animal seems to favour a habitat in open waters, specimens confined in a small cell showed themselves fairly hardy, and produced eggs somewhat freely for the first few days. These were approximately oval in outline, inclining to the *Citrina* type, the smaller pole being distinctly less obtusely rounded than the greater, and in one instance rising to a low knob-like prominence. One of these hatched out within seven days after extrusion. I observed that several adults crawling about were constricted at the third cervical segment. In confinement they soon settled down, and thereafter were loth to shift their quarters. Some examples seemed to remain for days together without changing their place. While feeding, the body was in incessant movement, swaying to right and to left, raising itself more or less upright, or lowering itself to a nearly prone position, whilst ever retaining its foothold.

The eggs measured from 65 μ to 70 μ in length, and from 48 μ to 54 μ in width.

Note on the Rotifera of Ponds, as compared with Lakes.

Neither physically nor biologically can any hard and fast line be drawn between lochs and ponds. In making the bathymetrical survey, the practice was to examine any body of water on which a boat was found, or could easily be placed, omitting as a rule those of less than quarter of a mile in greatest diameter.

Some lochans of less than quarter of a mile in length—for example, Lochan Dubh at Lochailort—were of such depth that the temperature and the biological phenomena showed a correspondence with our greatest lakes, rather than with shallow lakes or ponds. On the other hand, some very considerable lochs were so shallow that the temperature had the extreme range found in small ponds, and the biology corresponded.

The foregoing list of Rotifers is restricted to species found in lochs which were bathymetrically surveyed. When practicable, we also examined ponds adjoining the lochs for purposes of comparison, and periodical collections are being made from certain small ponds, in order to compare the annual cycle of changes with that which occurs in lochs. This investigation is still incomplete, and will be dealt with when finished. A full account of the Rotifera of ponds would be too extensive to be included here. At present it is only intended to contrast the relative frequency of the species in our list in lakes and ponds, and to describe a free-swimming Bdelloid which came to light in the course of these researches.

All the Rhizota in the list, except the species of *Conochilus*, *Floscularia pelagica*, and *F. mutabilis*, are commoner in ponds, and are not very commonly found in lakes. Even the powerful swimmer, *Pseudæcistes rotifer*, prefers ponds and ditches. Of the Bdelloida, the various genera are different in their habits. On the whole, the oviparous kinds are more at home in lakes, the viviparous in ponds, but there are exceptions. Most of the species of *Philodina* which we have recorded are very much at home in lakes, and several of them, with the related *Microdina*, are the most characteristic of lake-margin forms. *P. citrina*, *P. acuticornis*, and the two viviparous species are pond-dwellers.

The genus *Rotifer* is on the whole rare in lochs. I have found no species common in lochs except the parasitic *R. socialis*; *R. macroceros* is next in frequency, the others rare.

In ponds adjoining Loch Ness we found *R. vulgaris*, *R. citrinus*, *R. tardus*, *R. longirostris*, *R. macrurus* (which is not in our list as a lake species) all common and abundant. *R. neptunius* is frequent, and *R. trisecatus* not very rare in ponds. *R. macrurus* is most at home in bog-pools, and *R. longirostris* among dirty moss.

Many of the *Callidinæ* are ubiquitous—equally at home in ponds, lochs, and elsewhere. None are particularly characteristic of lake-margins, but *C. muricata*, *C. crucicornis*, and *C. incrassata* (not yet found in lochs) are true pond species.

The pellet-making *Callidinæ*, though well represented in our list, are with few exceptions properly peat-bog species. *C. elegans* (?), *C. pusilla*, and *C. longiceps* are

more adapted for lake or pond life. The others are bog- or moss-dwellers, except *C. annulatus* and *C. aspera*, which are commonly 'symbiotic' with hepatics on trees.

The Adinetadæ on our list are all moss-dwellers, and casual, though frequent, in lochs. *A. oculata*, which is not on the list, is a pond species.

The Ploïma are too numerous to be compared in detail. A large number of the pond species have not yet been seen in lakes, though there is no reason why they should not be expected sooner or later.

The Microcodidæ, active swimmers though they are, are pond species; the Asplanchnadæ, Synchætadæ, and Triarthradæ chiefly lacustrine.

The host of Notommatadæ are about equally divided, some of the species being eminently characteristic of lakes.

The Hydatinadæ and Rattulidæ are most frequent in ponds, the Dinocharidæ in bogs and ponds.

The remaining families of loricated Ploïma are fairly adapted to a lacustrine life, the Pterodinadæ among these being most restricted to ponds. In the Plœsomadæ are both lake and pond species.

Callidina natans, n. sp. (Plate II. figs. 8*a* to 8*i*.)

Specific characters.—Of moderate size, whitish. Free-swimming. When swimming, broadest at corona, tapering to very slender foot, with slight expansion in central part of trunk. Rostrum long, extended forward when swimming; lamellæ apparently united in single large hood, as in *Metopidia* and *Stephanops*; antenna equal to three-fifths diameter of neck, directed backwards. Jaws very long and narrow; teeth 2/2, 2/1, or 3/1, very excentric. Stomach large. Foot very slender, hardly tapering, one-fifth of total length, one-third formed by the terminal segment; spurs minute, acute; toes three, large. Food not moulded into pellets. Trunk closely plicate, in optical section elliptical. No processes seen on rostrum except lamellæ and brush of cilia. Vibratile tags narrow, parallel-sided, 14 μ long; three pairs seen.

Length when swimming, 400 μ; when creeping, scarcely greater. Diameter of corona, 90 μ; of neck, 55 μ; of trunk, 75 μ.

Owing to the habit of stretching the rostrum forward when swimming, the upper lip could not be clearly observed. The discs are large, and only separated by a small space (about quarter the diameter of one disc), across which stretches a hyaline membrane almost on a level with the discs. From time to time, as the animal turned slightly in swimming, a little sharp elevation was seen between the discs. This I regard, not as a 'ligule' proper, which should be an independent structure, but as probably the angle of meeting of the skin-folds so characteristic of the upper lip, and which form a similar angle in other species.

The rostral lamellæ are of rather unusual form. When fully extended they quite lose the appearance of being two-lobed presented by most rostral lamellæ, and look like a hood, gently curved forward at the tip (fig. 8*g*).

The jaws are exceptionally narrow, being only equalled by some of the pellet-makers, the shape being in those cases quite different. In this the outline of the jaw is nearly a perfect arc of a circle.

Central setæ were not observed on the discs.

On such short acquaintance it is impossible to suggest the affinities within the genus. Though no eggs were seen, the absence of fœtus places it in the oviparous, non-pellet-making section of *Callidina*, with *C. plicata*, etc. In appearance it has no close relationship with the other animals in the section.

Habits.—Free-swimming in company with *Brachionus pala* and *Anuræa valga*. When swimming, the rostrum and antenna are kept fully extended, the rostrum projecting in front of the corona, concealing the upper lip. From the broad corona to the toes, the general form is that of an elongate cone, though there is a narrowing at the neck and expansion in the central segments. The foot is also kept fully extended, even to the toes, and trails behind like a tail.

Under the cover-slip it continually tried to swim, but, having too little room, was often compelled to stop. It then wriggled on its side in an aimless fashion. The little foot was drawn into the somewhat heavy trunk and shot out again, curling about like a worm. It seemed to be unfamiliar with the use of the toes for creeping, and some time passed before it made attempts in that direction. Even when it got on its feet, the toes were never drawn into their sheath in the usual way, but kept extended to their full length.

The animal made its appearance in considerable numbers in a pond which dries up in summer, within a week after the pond filled at the beginning of winter. The pond is only a foot or two in depth, but when the collection was made it was calm and clear, and the collection was taken without disturbing the bottom; so there seems little doubt that it is a true swimmer, if only in shallow waters, and its behaviour under the confinement of the cover-slip confirms this.

Habitat.—In a pond which fills each winter, and dries in summer, at Nerston, East Kilbride. Fairly abundant on the day when it was detected, it has never been again found, though the pond has been examined in the same manner at regular intervals ever since. Fortunately, the original collection was sent to Mr Bryce, who found some of the animals, and confirmed my diagnosis in some particulars, while agreeing with me that it was distinct from any species previously seen.

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EXPLANATION OF PLATES.

The figures are all drawn by me from living animals, except that of *Notommata pumila*, which is drawn by Mr F. R. Dixon-Nuttall from a specimen mounted by Mr Rousselet, and the jaws of the same species, which are copied from a sketch by Mr Rousselet. The drawings of the whole animals are as far as possible drawn to the same scale, so that some idea of comparative size may be got. *Pseudæcistes rotifer* was so large that it had to be drawn on a reduced scale.

Plate I.

1. *Philodina flaviceps*, n. sp., Bryce.
   - *a*, dorsal view of whole animal, feeding.
   - *b*, ventral view, creeping.
   - *c*, jaw.
   - *d*, spurs, common variety.
   - *e*, spurs, a rare variety.
   - *f*, spurs and toes, commonest form.
2. *Philodina brevipes*, Murray.
   - *a*, dorsal view, showing whiskers and tags.
   - *b*, rostral tip, with whiskers and motile setæ.
   - *c*, foot, illustrating mode of telescoping.
3. *Philodina acuticornis*, Murray. Rostral tip.
4. *Callidina crenata*, Murray. Head.
5. *Callidina scarlatina*, Ehr. Spurs elongated by mucus.
6. *Callidina magna*, Plate. Head, showing large processes on discs. Wreath omitted.

Plate II.

7. *Philodina hamata*, n. sp.
   - *a*, dorsal view, feeding.
   - *b*, antenna, to same scale as whole animal.
   - *c*, rostral tip, ventral side.
   - *d*, rostral tip, lateral view.
   - *e*, jaw.
   - *f*, spurs, with basal fold, dorsal view.
   - *g*, spurs and toes, from the side.
   - *h*, spurs, another dorsal view.
   - *i*, spurs and toes, ventral side.
8. *Callidina natans*, n. sp.
   - *a*, dorsal view, swimming.
   - *b*, lateral view.
   - *c*, jaws.
   - *d*, optical section of trunk.
   - *e*, spurs, approximated.
   - *f*, spurs, separated.
   - *g*, rostral hood, dorsal view.
   - *h*, rostral tip, from below.
   - *i*, spurs and toes.
9. *Philodina acuticornis*, Murray.
   - *a*, dorsal view, feeding.
   - *b*, lateral view.
   - *c*, normal spurs.
   - *d*, very slender spurs elongated by mucus.

Plate III.

10. *Callidina habita*, var. *bullata*, n. var.
    - *a*, dorsal view.
    - *b*, jaws, mouth and gullet.
    - *c*, dorsal view of foot.
    - *d*, lateral view of foot.
11. *Callidina longiceps*, n. sp.
    - *a*, the animal in its house.
    - *b*, head, more enlarged.
    - *c*, jaw.
12. *Callidina pusilla*, Bryce. Variety.
    - *a*, lateral view, showing prominent lower lip.
    - *b*, head and neck, dorsal view.
    - *c*, head, ventral view.
13. *Callidina hexodonta* (Bergendal). Head.

PLATE IV.

14. *Adineta tuberculosa*, Janson.
15. *Rotifer socialis* (Kellicott).
    a, animal with foot partially retracted.
    b, small-scale drawing, to show proportions.
    c, jaw.
    d, antenna.
    e, foot, last three segments, and toes.
16. *Callidina aspera*, Bryce.
    a, dorsal view, feeding.
    b, jaw.
    c, portion of trunk, showing tubercles.
17. *Microdina paradoxa*, Murray, with jaws protruded, biting a filament of Alga.

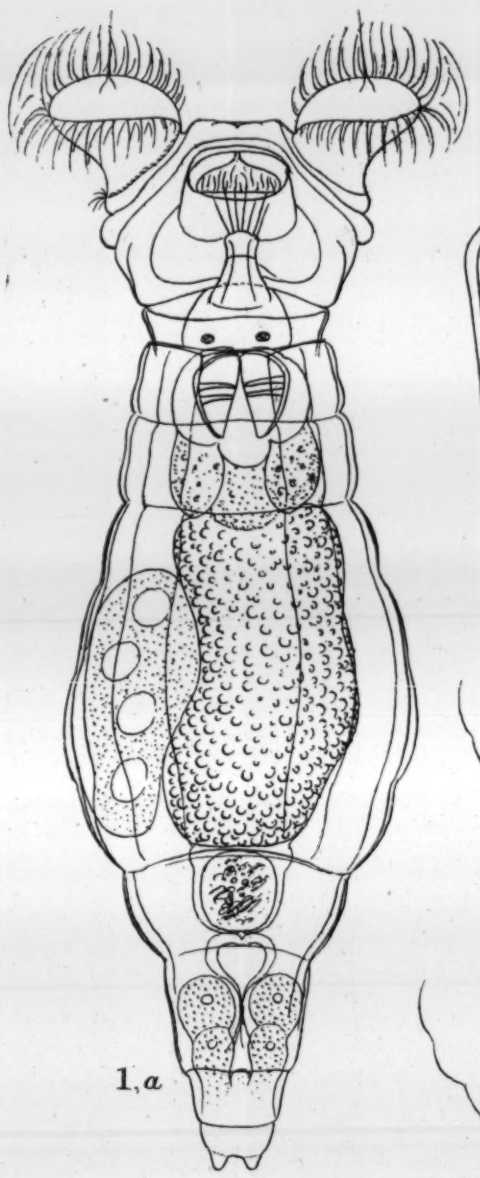
PLATE V.

18. *Pseudœcistes rotifer*, Stenroos.
    a, the animal swimming.
    b, teeth of one jaw.
19. *Stephanops tenellus*, Bryce.
    a, dorsal view.
    b, lateral view.
20. *Rotifer trisecatus*, Weber.
    a, jaw.
    b, foot, from ventral side.
    c, foot, lateral view of penultimate segment and spurs.
21. *Philodina macrostyla*, Ehr. Rostral tip, to show pairs of tactile setæ.
22. *Rotifer tardus*, Ehr. Head, showing central setæ.
23. *Rotifer vulgaris*, Schrank. Head, showing central setæ.
24. *Albertia intrusor*, Gosse.
    a, dorsal view.
    b, lateral view.
    c, lateral view of young.
    d, dorsal view of young.

PLATE VI.

25. *Notommata pumila*, n. sp., Rousselet.
    a, lateral view, drawn by F. R. Dixon-Nuttall.
    b, jaws, after drawing by Mr Rousselet.
    c, toes, dorsal view.
26. *Proales daphnicola*, Thompson.
    a, lateral view, head applied to skin of worm.
    b, five examples adhering to one worm.
    c, jaws.
27. *Colurus tesselatus*, Glascott.
    a, dorsal view.
    b, lateral view.
28. *Plœsoma*, sp.?
    a, probably *P. triacanthum* (Bergendal).
    b, larger species, also with three dorsal spines, and two additional lateral spines.

MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE I



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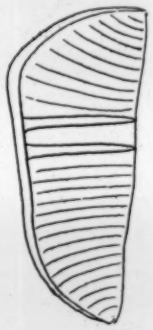
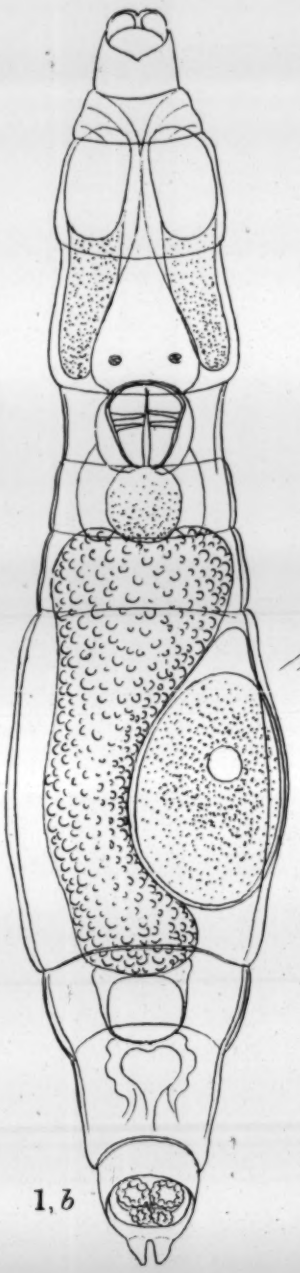


1, *c*

1, *d*

1, *e*



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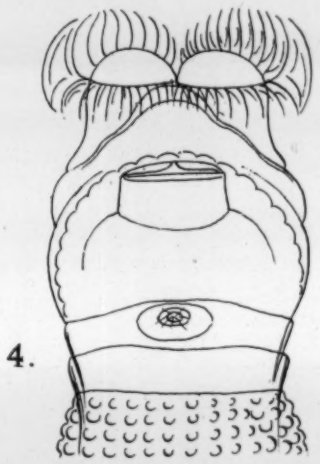

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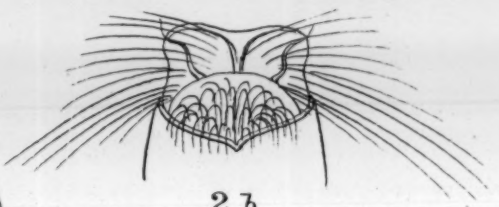

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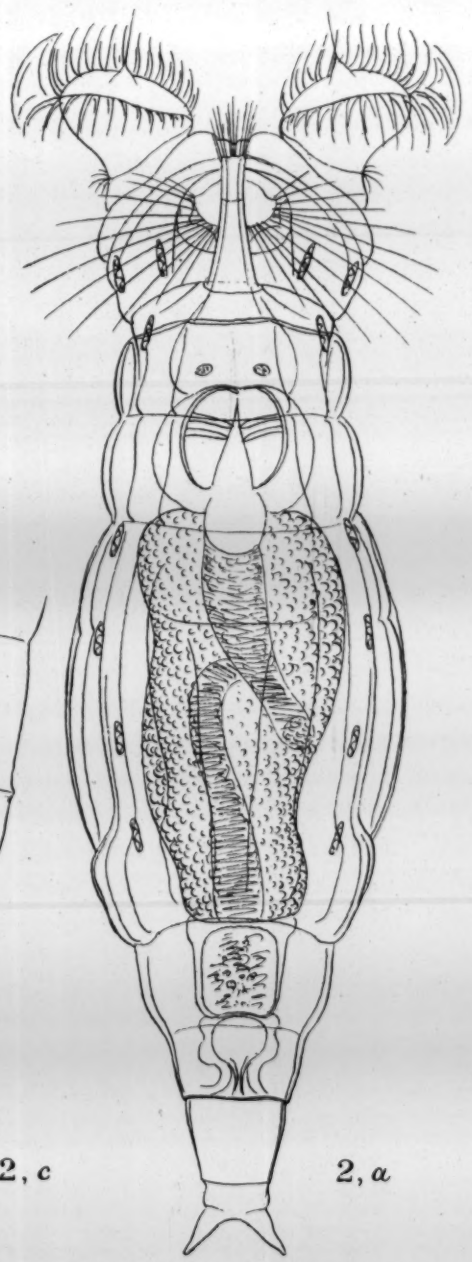

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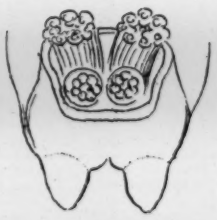

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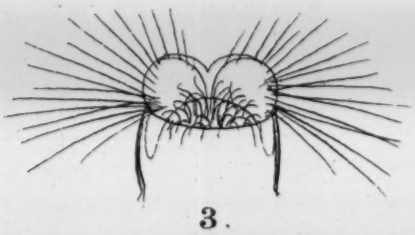

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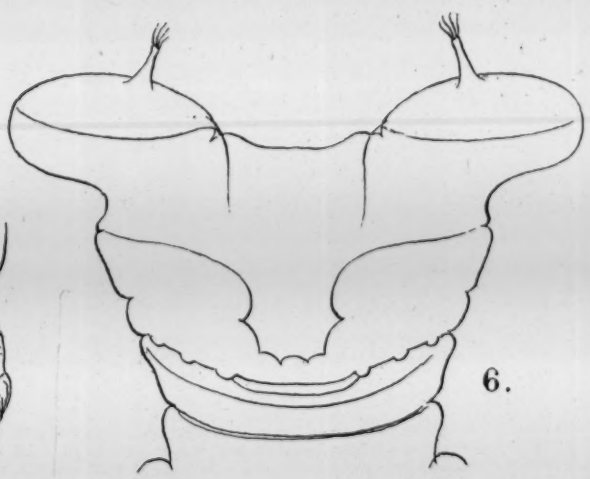

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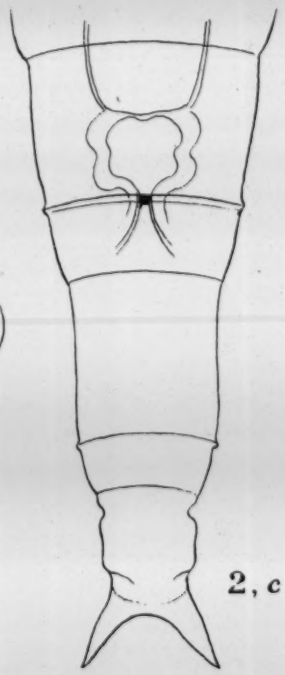

2, *c*

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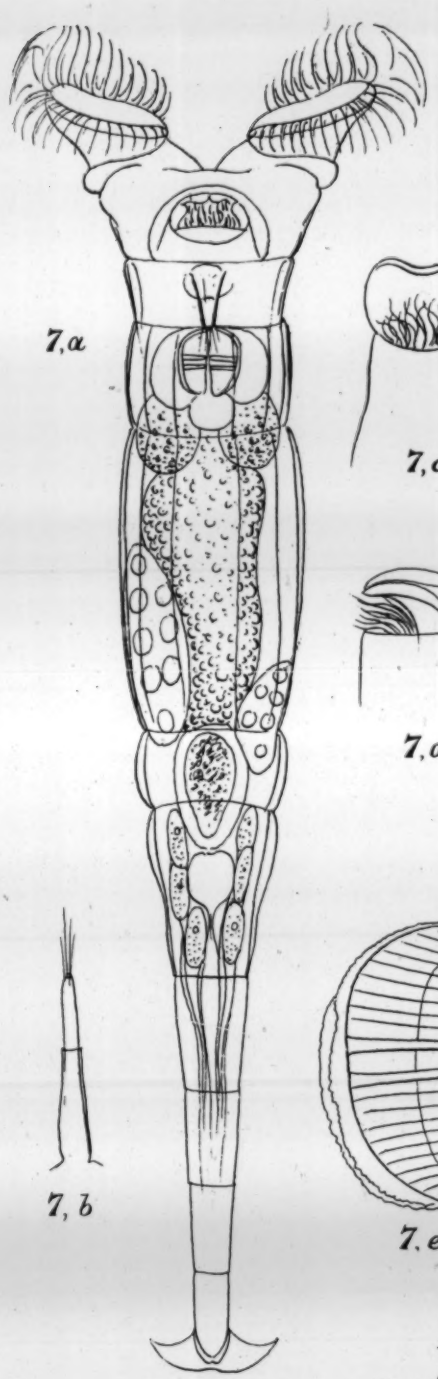
1, PHILODINA FLAVICEPS, n. sp. Bryce. 2, PHILODINA BREVIPES, Murray. 3, PHILODINA ACUTICORNIS, Murray.
4, CALLIDINA CRENATA, Murray. 5, CALLIDINA SCARLATINA, Ehr. 6, CALLIDINA MAGNA, Plate.

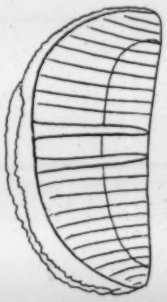
MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE II


7, a

7, b

7, c

7, d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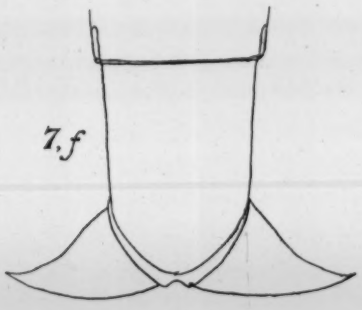
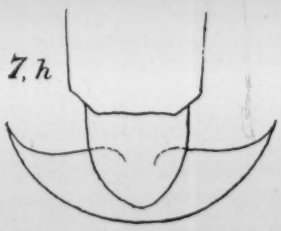
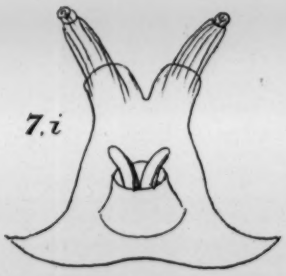

7, f

7, g


7, h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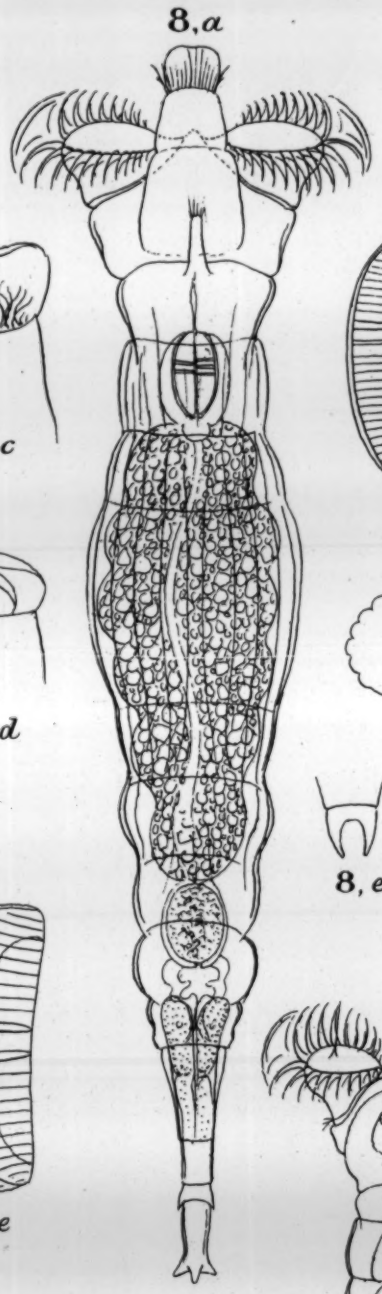
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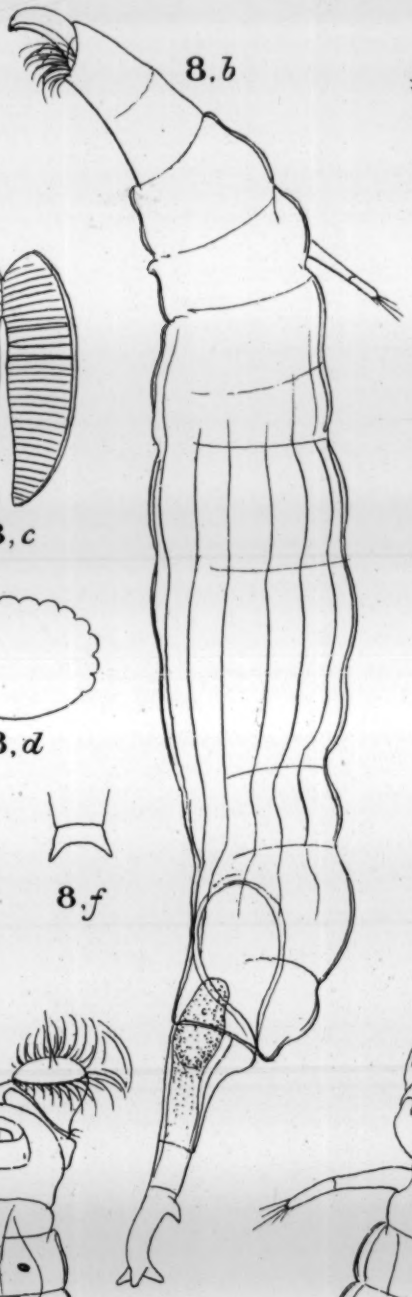
8, b

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8, e

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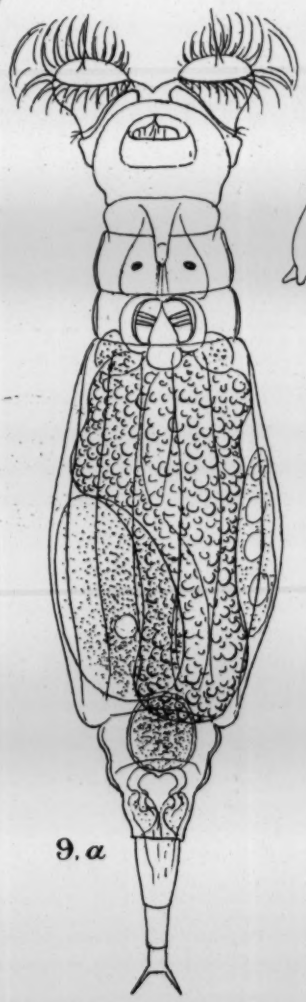
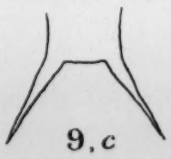
8, g

8, h

8, i


9, a

9, d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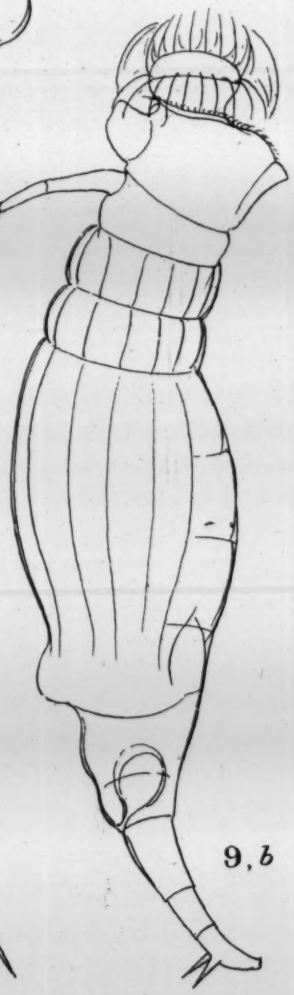
9, b

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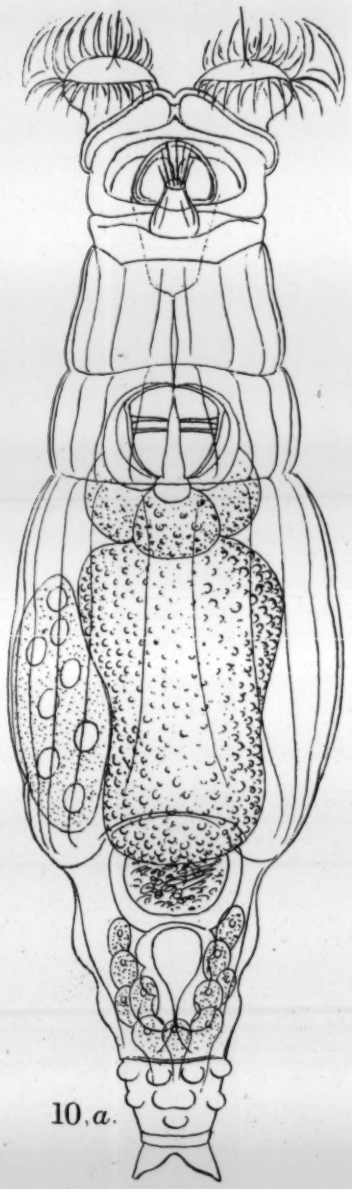
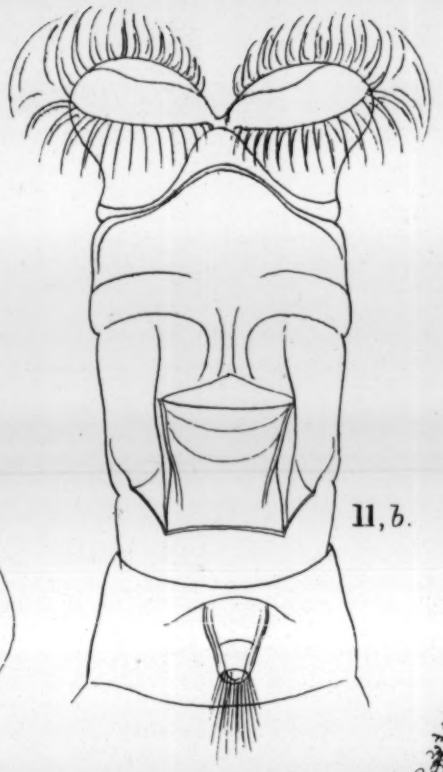
7. PHILODINA HAMATA, n. sp. 8. CALLIDINA NATANS, n. sp. 9. PHILODINA ACUTICORNIS, Murray.

MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE III.

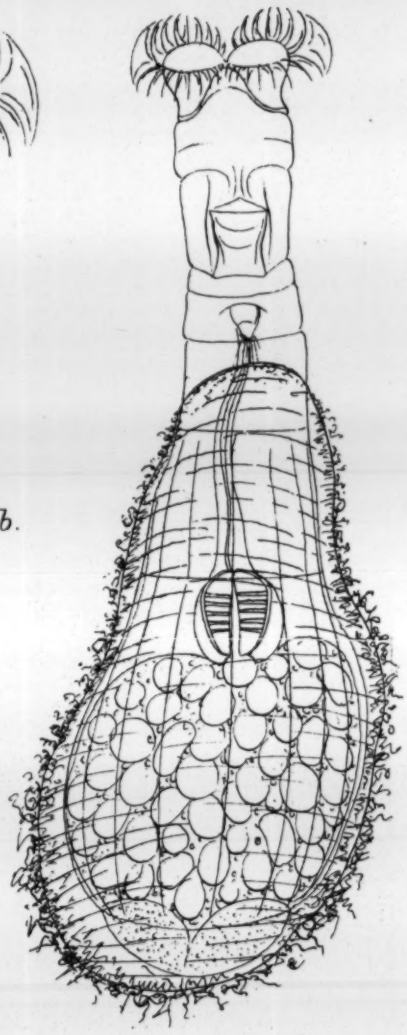


10, *a*.

10, *b*.



11, *b*.



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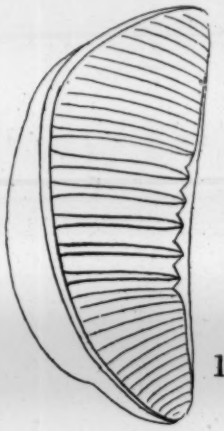

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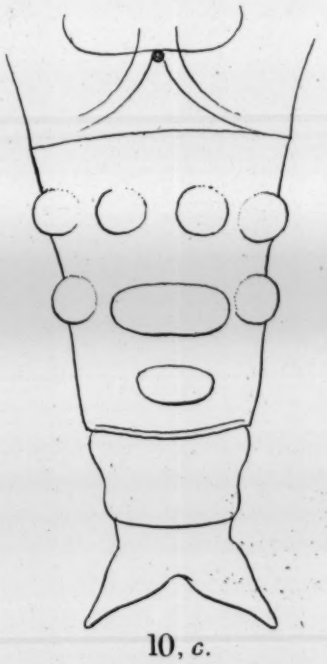

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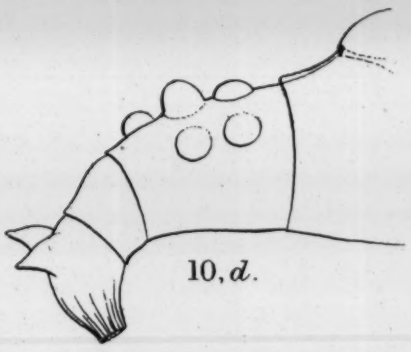

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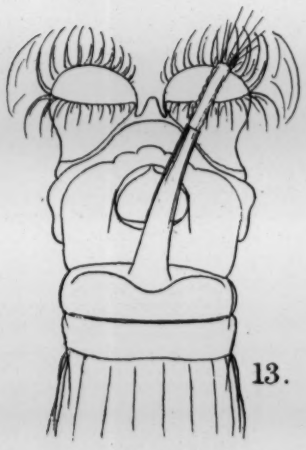

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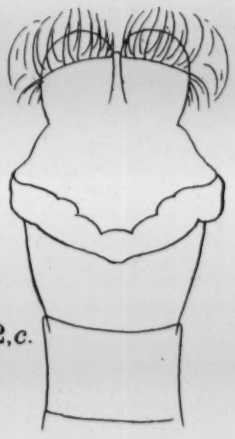

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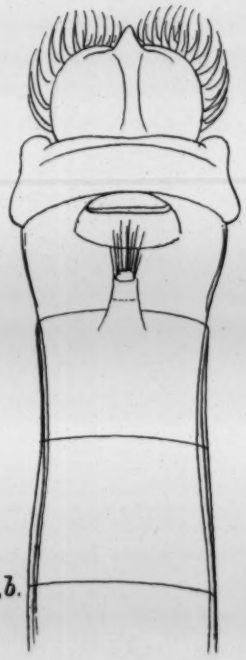


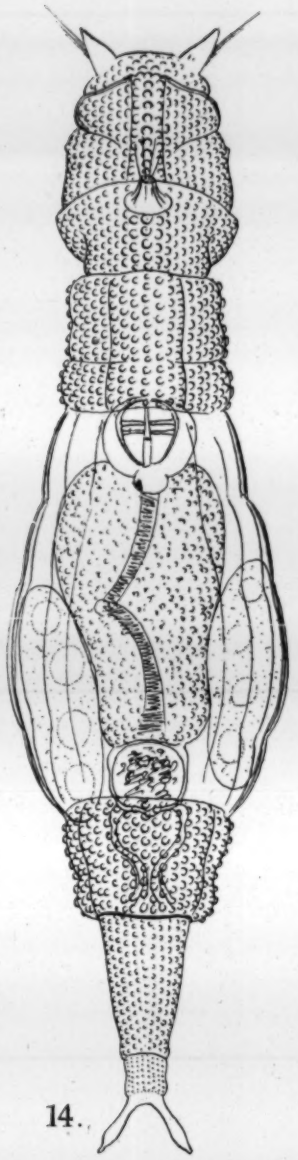
12, *b*.

12, *a*.

M'Farlane & Erskine Lith Edin.r

10 CALLIDINA HABITA, var. BULLATA, n. var. 11. C. LONGICEPS, n. sp. 12, C. PUSILLA, Bryce, var.
13, CALLIDINA HEXODONTA, Bergendal.

MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE IV.



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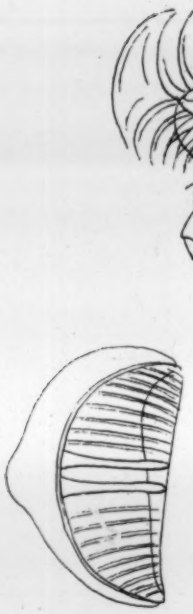
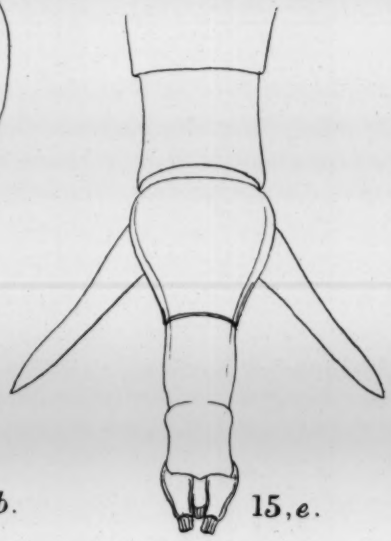


15, *c*

15, *d*

15, *b*.



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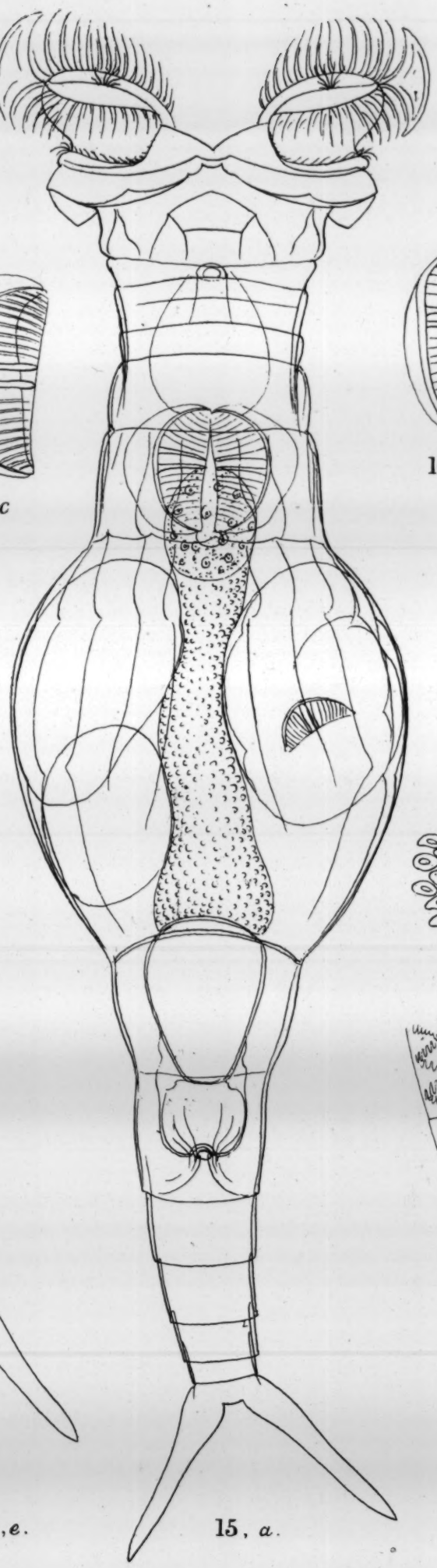

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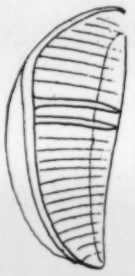

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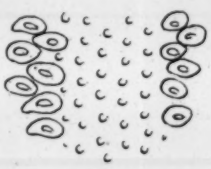

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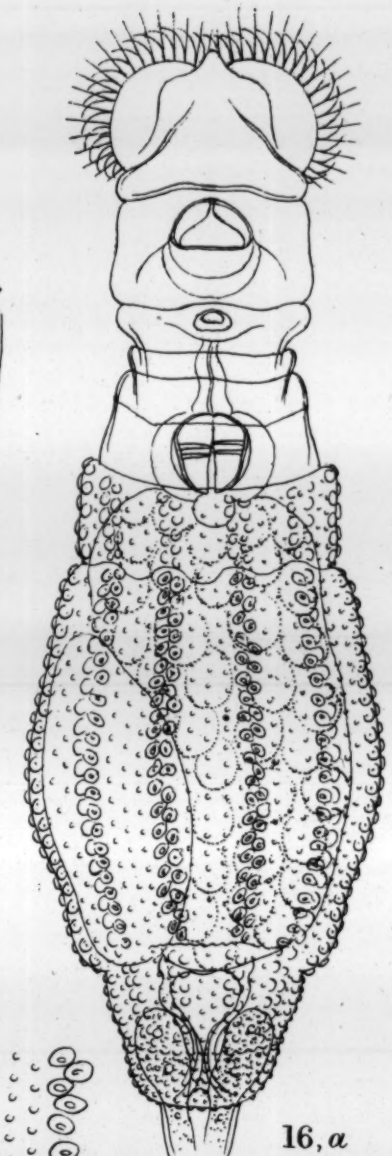


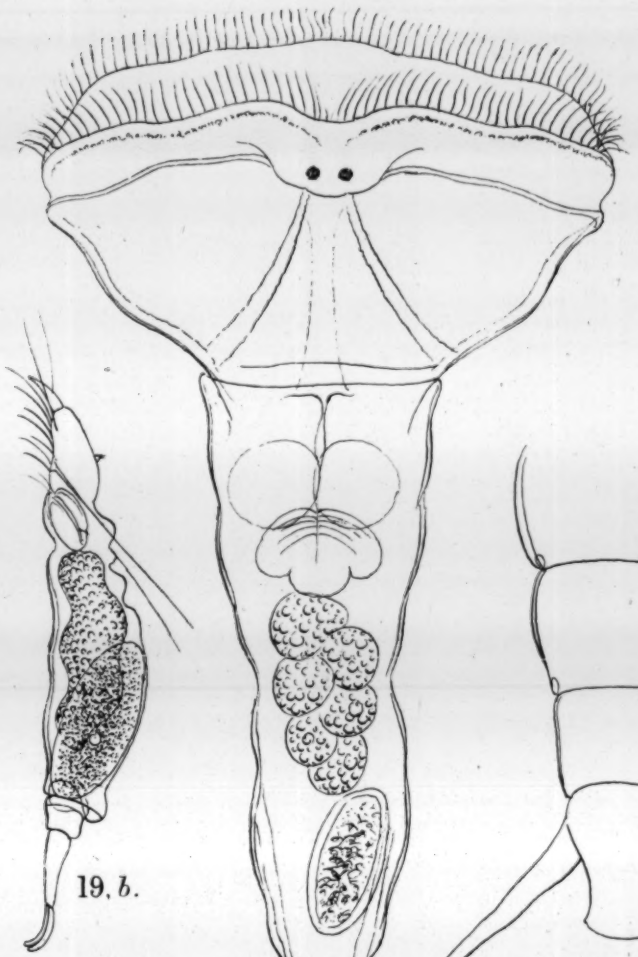
16, *a*

17.

M.Farlane & Erskine, Lith. Edin.r

14, ADINETA TUBERCULOSA, Janson. 15, CALLIDINA SOCIALIS, Kellicott. 16, CALLIDINA ASPERA, Bryce.
17, MICRODINA PARADOXA, Murray.

MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE V.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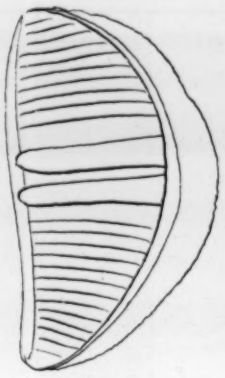
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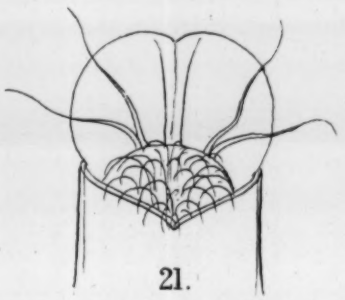
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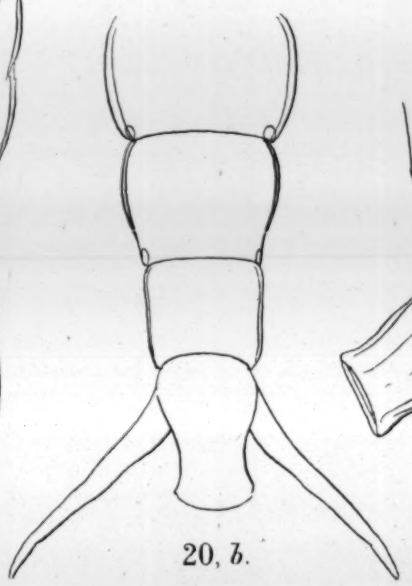
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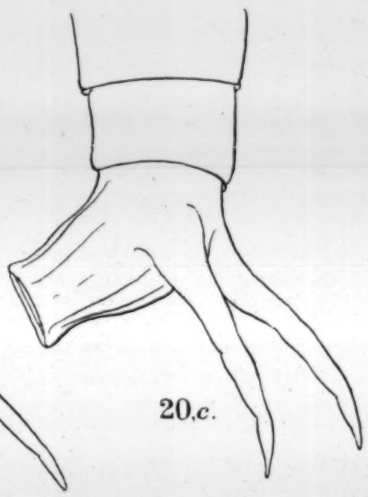
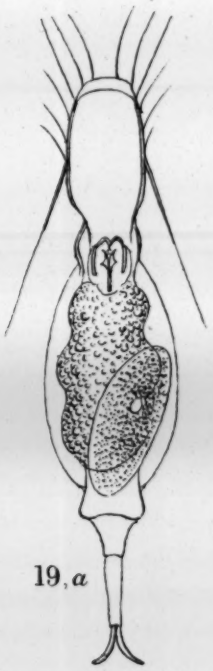

20, *c*.

24, *c*.

24, *d*.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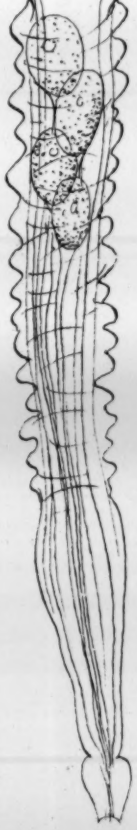
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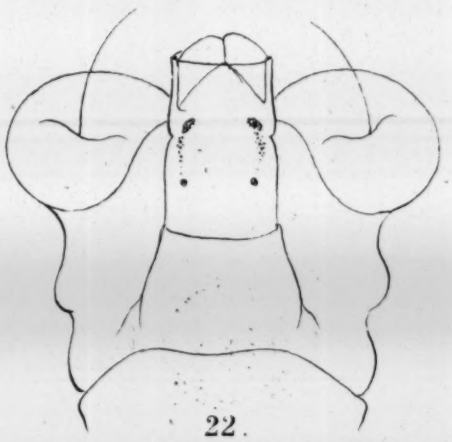
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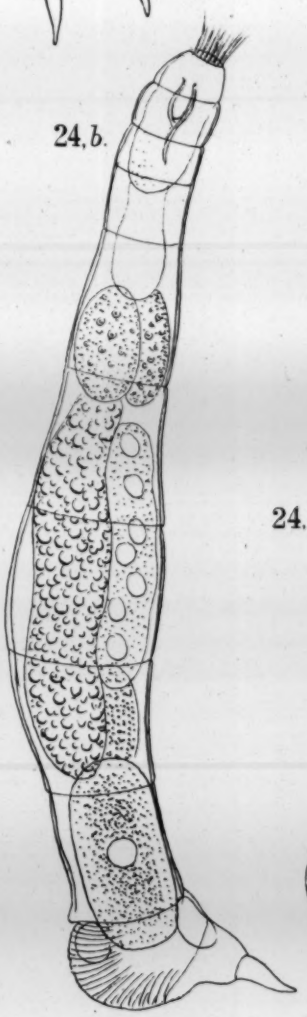
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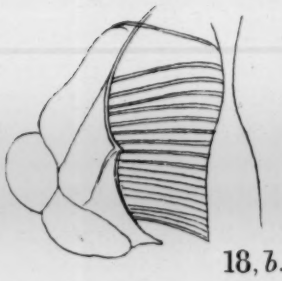
24, *a*.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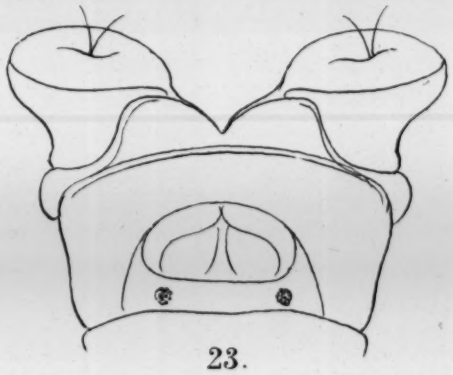
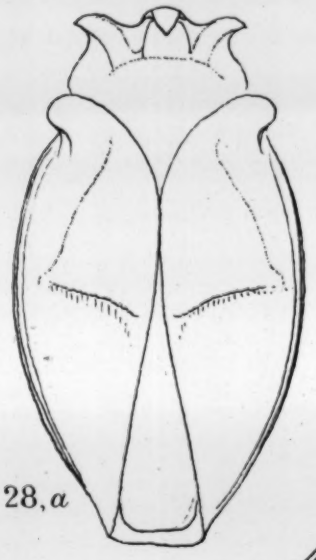

23.

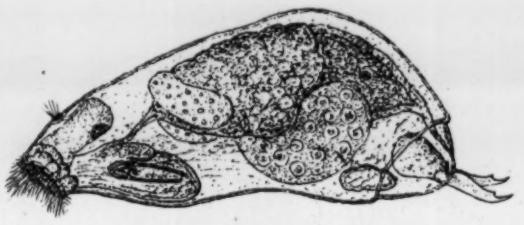
M.Farlane & Erskine, Lith. Edin.r

18, PSEUDŒCISTES ROTIFER, Stenroos. 19, STEPHANOPS TENELLUS, Bryce. 20, ROTIFER TRISECATUS, Weber.
21, PHILODINA MACROSTYLA, Ehr. 22, ROTIFER TARDUS, Ehr. 23, ROTIFER VULGARIS, Schrank. 24, ALBERTIA INTRUSOR, Gosse.

MURRAY: THE ROTIFERA OF THE SCOTTISH LOCHS.—PLATE VI.

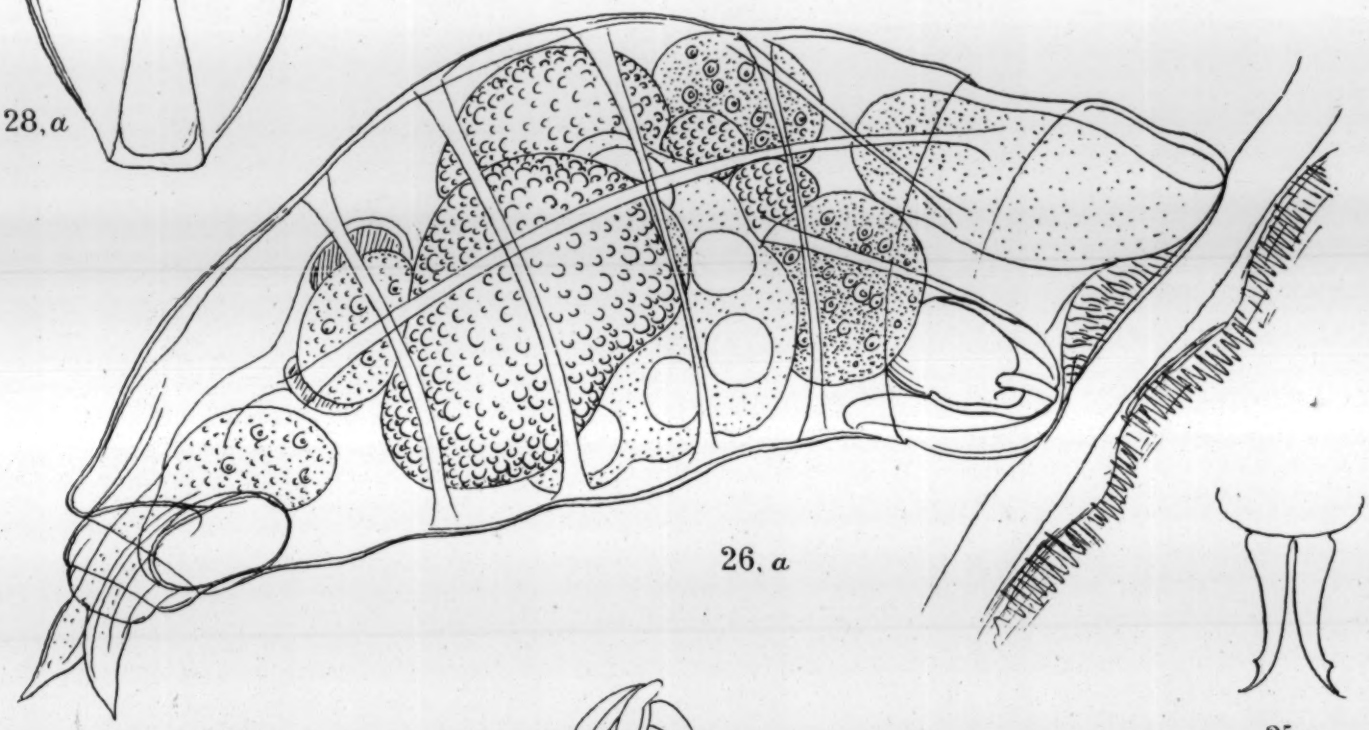


28, *a*



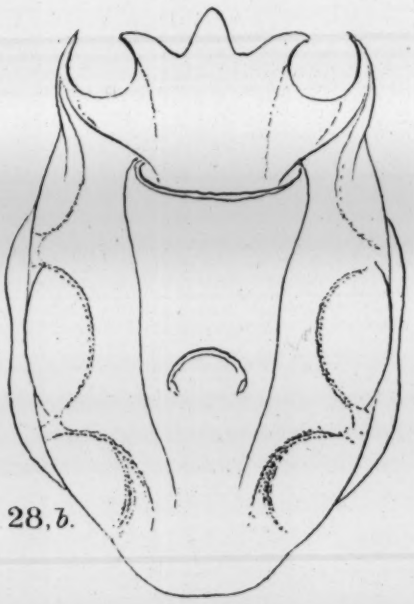
25, *a*.

25, *b*.



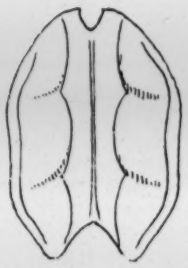
26, *a*

25, *c*.



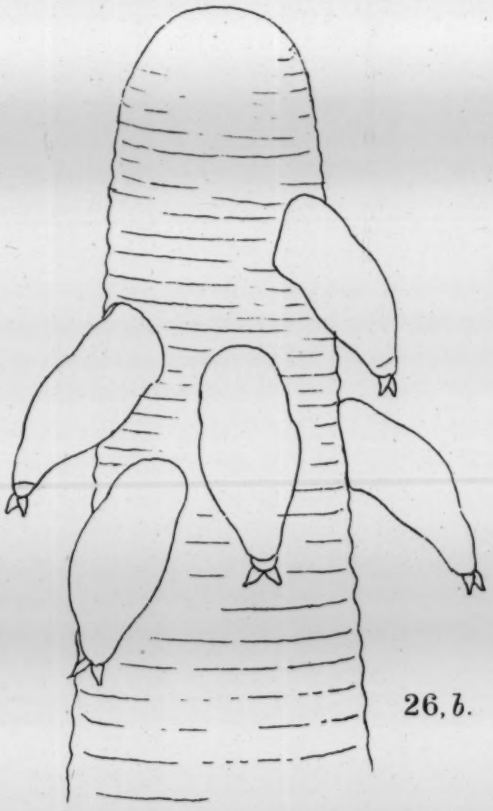
28, *b*.

26, *c*.



27, *a*

27. *b*.



26, *b*.

McFarlane & Erskine. Lith Edin.r

25, NOTOMMATA PUMILA, n. sp. Rousselet. 26, PROALES DAPHNICOLA, Thompson. 27, COLURUS TESSELATUS, Glascott.
28, PLŒSOMA TRIACANTHUM, Bergendal?

VIII.—On the Elevation of the Boiling Points of Aqueous Solutions of Electrolytes.

By Rev. S. M. Johnston, D.Sc.

(MS. received 8th February 1906. Read 19th February 1906. Issued separately, 11th July 1906.)

(The expense of this research was partly covered by grants from the Moray Endowment and the Carnegie Trust.)

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PART I.

An Improved Method of Determining Elevation.

It has been known for a length of time that the presence of a non-volatile substance diminishes the vapour pressure of the solvent in which it is placed, and as the boiling point of a solvent or a solution is the temperature at which the vapour pressure is just equal to, or overcomes the pressure of the atmosphere, it follows that a solution has a higher boiling point than the solvent. Amongst the first experimenters in this field were Faraday,* Legrand,† Griffiths,‡ and Raoult.§ To Raoult we owe much for his development of the subject.

Perhaps from the experimental point of view the subject owes more to Beckmann‖ than any other. Not only do we owe to him the very delicate thermometer used in boiling-point work, but also the experimental method whereby determinations may be made. He submitted the apparatus designed by himself to the German Society of Scientists, September 1889, and shortly afterwards published a description of it. Since then his apparatus has undergone several modifications.¶ In the various forms of boiling-point instruments which have been designed, one might trace the difficulties which gather around research of this kind.

* *Ann. Chim. Phys.*, 20, 324.
† *Ann. Chim. Phys.*, 59, 423.
‡ *Pogg. Ann.*, 2, 227.
§ *Compt. Rend.*, 103, 1125.
‖ *Ztschr. phys. Chemie*, 3, 603 (1889), 4, 532 (1889).
¶ *Ztschr. phys. Chemie*, 21, 245 (1896), 15, 656 (1894).

Not a few other observers are worthy of mention, and amongst these the following: HITE,* SAKURAI,† LANDSBERGER,‡ SMITZ,§ JONES,‖ BILTZ,¶ and WALKER and LUMSDEN.**

Before the best results can be obtained, one must have the most suitable instrument. Consequently, as boiling-point results have not been satisfactory when water has been used as solvent, almost every observer has designed a special form of instrument.

When water has been used as solvent, the determinations which have been made from boiling-point data have been principally molecular weights.

It would seem that aqueous solutions have presented special difficulty. JONES†† says: "It is a misfortune for the boiling-point method that aqueous solutions cannot be used satisfactorily."

My observations were at first directed to find out, if possible, a method whereby this difficulty might be overcome. After experimenting for a considerable time with the older and most recent forms of the Beckmann boiling-point apparatus, and after a careful consideration of several others, I designed a tube of the Jones-Beckmann type, a sketch of which is given in fig. 1. It embraces what experience taught me were the best points in the Jones and Beckmann instruments, with the object of making a series of experiments on the same salt for widely varying concentrations.

The tube F had two side tubes, G and D, attached, the small tube, G, for the admission of salt pellets with a rubber stopper, and the larger one, D, fitted with a condenser of the Beckmann pattern. The thermometer used was one of BECKMANN'S, reading to hundredths of a degree, which passed through a rubber stopper B into the boiling tube.

Garnets, platinum tetrahedra, and platinum foil were used for filling material, and the thermometer was placed so as to be a little above the filling material, the latter being arranged in what was considered from experience the best possible way. The garnets were placed in the bottom of the tube to a height about one centimetre below the position the thermometer would take up, platinum tetrahedra were then added, it being found desirable to have enough of these to cover completely a cross-section of the tube, when all the tetrahedra were resting on the garnets. A few more of the latter were added, and small pieces of platinum foil placed on top of all, underneath the position the lower extremity of the bulb of the thermometer should take up. The garnets and platinum tetrahedra steadied the ebullition and checked superheated vapour on its way towards the thermometer. A cylinder,‡‡ P, of platinum foil was pressed down into the garnets a little, and rose, as is indicated in the sketch given, considerably above the surface of the solvent or solution which the tube might contain. This platinum cylinder served two purposes: it warded off radiation and kept the cooled liquid from the condenser from coming into contact with the thermometer before it

* *Am. Chem. Journ.*, 17, 507.
† *Journ. Chem. Soc.* (London), 61, 989.
‡ *Ber. der Chem. Ges.*, 31, 458.
§ *Ztschr. phys. Chemie*, 39, 409 (1902).
‖ *Am. Chem. Journ.*, 19, 581, also 31, 340 (1904).
¶ *Ztschr. phys. Chemie*, 40, 208 (1902).
** *Journ. Chem. Soc.*, 73, 509 (1898).
†† *Physical Chemical Methods* (JONES), p. 31.
‡‡ *Physical Chemical Methods* (JONES), p. 35.

had been raised again to the boiling temperature. When the boiling tube was in position it was surrounded by a glass cylinder A, of larger diameter, the space between

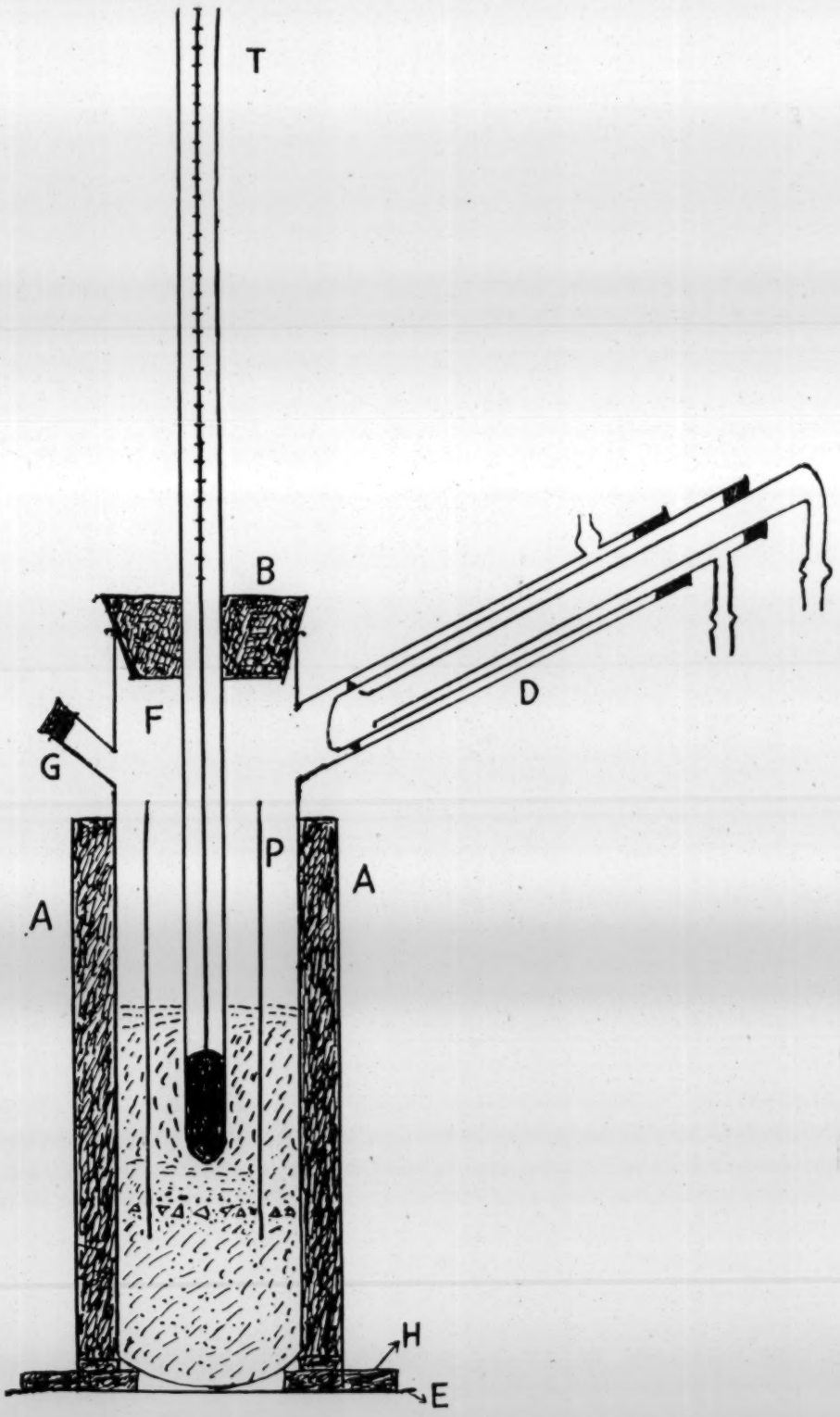

FIG. 1.

being packed with asbestos wool, which reached to the height shown. The instrument rested on an asbestos board H with a circular opening in its centre, covered by a sheet

of asbestos paper E. It was supported on a piece of wire gauze by a retort-stand. The wire gauze and asbestos paper preserved the tube from the direct action of the gas-flame, the latter being used as the source of heat, the heating being direct.

To ward off draughts a circular cylinder of zinc was used in two pieces, one of which could be removed when desired. Three sizes of boiling tubes were used, one for dilute solutions capable of containing 50 cubic centimetres of solvent or solution to the height indicated; the others were a 25 cubic centimetre and a 15 cubic centimetre tube for moderately dilute and concentrated solutions, each being so arranged that the liquid, solvent, or solution reached the same height, and that the same platinum cylinder suited all three.

With the apparatus arranged in this way, a steady boiling temperature was quickly attained.

A Beckmann reading-glass was used for making the readings, the thermometer being slightly tapped before the readings were made. In that way it was possible to read to one-thousandth of a degree. Notwithstanding the delicacy of the thermometer, it was possible to bring it to a perfectly steady position, not unfrequently for several minutes.

The water used was redistilled to guard against impurities. The filling material after each series of experiments was thoroughly cleansed with boiling water and dried before being used again. The platinum foil in addition was heated in a Bunsen flame.

In order to find the change in concentration due to boiling, experiments were made to determine the amount of vapour present in the tube during ebullition. The determination was founded upon specific gravity observations made by means of a pyknometer, and using in the boiling tube a quantity of the solution of known weight, the volume corresponding to that to be used in experiments. The specific gravity of the solution was first measured at 15° Centigrade before being placed in the boiling tube, and then after boiling in the tube for some time. In the latter case the boiling solution was withdrawn from the boiling tube in a pipette, in which it was cooled with as little loss of vapour as possible. From these data the percentage compositions were determined graphically by the aid of tables.* These being known, the vapour determination was readily made. The amount was found to vary from ·3 to ·56 of a gramme, and was allowed for.

Series of solutions were made by the addition of compressed pellets of salt successively to the solvent or solution during ebullition. The pellets were made at first by the aid of a steel press, but later by one with ivory fittings, to safeguard their purity, this being specially important where deliquescent salts were the subject of research.

The procedure adopted was to bring the solvent to a steady boiling temperature, which was noted. Then pellet after pellet of salt was added at intervals of from twenty to twenty-five minutes, the boiling temperature of the successive concentra-

* B. A. Report on the Present State of our Knowledge of Electrolysis and Electro-chemistry (1893).

tions being noted. It was found essential to the success of an experiment to allow at least twenty minutes for the diffusion of the salt.

Corresponding to the successive readings of the thermometer, successive readings of the barometer were made, in order that any change in atmospheric pressure might be allowed for. The barometer gave readings to an amount corresponding to an elevation of 0·004° Centigrade, but could be estimated to the equivalent of 0·002° Centigrade.

The salts used were supplied by Messrs MERCK & Co. as specially pure, and were tested analytically and spectroscopically.

In the calculation of results ionization coefficients were necessary at high temperatures, as near the boiling point as possible. These were obtained in several instances from conductivity values as given by KRANNHALS * (later from my own observations), as follows. KRANNHALS gives the molecular conductivity at 99·4° Centigrade for solutions containing one, one-half, one-fourth, one-eighth, etc., and one-thousandth gramme equivalents per litre. The ionization at any of these was obtained by dividing the conductivity value, as given by KRANNHALS, by the value at one-thousandth of a gramme equivalent. The concentration ionization curve was drawn for the range of a series of experiments. From the amount of salt added to the solvent the percentage composition was obtained, and from this, by the aid of tables,† the concentration in gramme equivalents per litre; the ionization was then determined graphically from the above-mentioned concentration ionization curves. KRANNHALS claims to work with an error limit of from 2 to 3 per cent. Having repeated many of his experiments I found this claim well justified.

SCHALLER and LYLE, and HOSKING have also done some conductivity work at 99° or 99·4° Centigrade. KRANNHALS' values were chosen because they were best suited to series of experiments.

LYLE and HOSKING‡ deal chiefly with sodium chloride solutions. SCHALLER § worked principally at 256, 512, and 1024 litres per gramme equivalent.

Values up to 80° Centigrade have been given by TRÖTSCH,‖ and CAMPETTI and NAZARI,¶ which would be too low a temperature for my purpose. Those who have given conductivity values to 99° or 99·4° have only given them to about one-thousandth gramme equivalent per litre, which dilution could scarcely be supposed to give the molecular conductivity at infinite dilution for every salt.

I have used KRANNHALS' conductivity values for KCl, KBr (dilute solutions), $NaNO_3$, KNO_3, and NaCl (dilute solutions).

When calculating the results obtained by experiment, *at first*, total elevations above the boiling point of the solvent were used. The calculations were made from the formula

$$C = \frac{m.W.E}{(1+\overline{n-1}\alpha)w},$$

* *Zeit. für phys. Chem.*, 5, 250 (1890).

† B. A. Report on the Present State of our Knowle lge of Electrolysis and Electro-chemistry (1893).

‡ *Phil. Mag.* (6), 3, 487 (1902).

§ *Zeit. für phys. Chem.*, 25, 497.

‖ *Wied. Ann.*, 41, 259 (1890).

¶ *Acc. Sci. Torino*, 40, Nos. 2 and 3, pp. 155, 163 (1904–5).

where C is the value of the so-called boiling-point elevation constant expressed per gramme particle (molecule or ion) in one gramme of solvent—

m = molecular weight of salt added.
W = weight of solvent used in grammes.
w = weight of salt added in grammes.
a = ionization coefficient.
n = number of free ions into which a molecule of salt dissociates.
E = elevation of boiling point.

From this formula values of C were obtained, at one time high, at another low, when compared with theory. Thus for potassium chloride the values 858, 704, 684, 643, 614, 596, 572 were obtained from one series; a second series gave 460, 467, 514, 518, 523. For potassium nitrate the values were 637, 617, 603, 573, 571, 549, 547, 540, and a second series gave 874, 702, 696, 686, 643, 608, 609, 593; for a third series the values were 605, 556, 550. For sodium nitrate 518, 516, 520, 529, 534, 530, 535. For sodium chloride 617, 621, 592, 587, 579.

Such values as these being obtained, it was desirable to see what values would be given by calculations from the boiling-point data of other experimenters. Elevations of boiling point as given by BILTZ* gave for potassium nitrate as values 638, 589, 596, 628; and for sodium chloride 585, 598, 611, 609.

Those given by WALKER and LUMSDEN† gave for potassium nitrate 648, 618; for sodium chloride 598, 593; and for potassium bromide 620, 614, 645, 665.

SMITZ's‡ elevations gave for sodium chloride 463; for potassium chloride 497; for potassium nitrate 522; and for sodium nitrate 594.

In discussing the meaning of the high and variable values of the elevation constant which have just been given, I have considered (1) whether they are due to error in correcting for change of atmospheric pressure, (2) to overheating.

(1) To test the values obtained under the first supposition I set up two similar boiling-point apparatus. The gas pressure was equalised by the use of a three-way tube, and two Bunsen burners exactly the same were used. The strength of the source of heat was therefore the same for each tube. The quantity of solvent used for each was 25 cubic centimetres. The one tube was used for solutions, the other for solvent. The readings in each instance were taken from Beckmann thermometers reading to one-hundredth of a degree. In this way it was possible to obtain a thermal register of the change of atmospheric pressure during the observation of boiling-point elevations.

For a series of experiments, readings were made of the barometer, the boiling point of the solvent, and that of solutions of sodium bromide. The observed boiling temperatures of solutions were then corrected by the readings of the barometer, and also by the thermometer in the tube containing the solvent.

* *Practical Methods for determining Molecular Weights*, translated by JONES and KING, p. 189.
† *Journal of the Chemical Society*, **73**, 502 (1898).
‡ *Zeit. für phys. Chemie*, **39**, 420.

The following are the corrected readings:—

By barometer, . .	2·320	2·435	2·525	2·888
,, thermometer, .	2·320	2·435	2·527	2·888
,, barometer, . . .	3·179	3·631	4·036	4·405
,, thermometer, .	3·179	3·629	4·034	4·403
,, barometer, . . .	4·866	4·876	4·892	
,, thermometer, . .	4·868	4·874	4·890	

These figures indicate only a slight difference between barometric and thermal corrections for change in atmospheric pressure, which could not account for the large values of the elevation constant which have been obtained, but might account for small variations in its value for dilute solutions.

(2) To find out if the high values were due to overheating, I took two courses. First I determined the boiling point of the same solution several times, and found the corresponding elevation constant to have, in all cases, approximately the same large value. Had overheating been the cause of the large values of the constant when compared with theory, one would not expect to be able to repeat a high value, much less to repeat it several times, as the amount of overheating would be likely to vary considerably. Secondly, in the case of each of several salts I made duplicate series of observations of the elevation of the boiling point for solutions of different concentrations, and plotted curves with grammes of salt added as ordinates and elevation of boiling point as abscissæ. The observations are given in a former paper,* but the curves obtained are given below (figs. 2 to 4). In the case of each salt the duplicate series gave different values for the elevation, and the curves are consequently not coincident; but whilst not coincident, they are smooth and parallel. If the values of the elevation were vitiated by overheating, the amount of overheating in one series must have exceeded that in the other by a constant amount—a quite improbable assumption.

In connection with the above it may be interesting to note what BILTZ † and LUTHER ‡ say. BILTZ: "For the attainment of exact temperature adjustment it is necessary to maintain an extremely energetic boiling." LUTHER,§ quoted by BILTZ: "Finds it indispensable to maintain an energetic, and indeed stormy boiling, for the better adjustment of temperature." Obviously, therefore, neither of these observers considered overheating as the cause of the discrepancy between the observed and the theoretical values of the boiling-point constant.

It would therefore seem that the high values obtained for the elevation constant are not due either to error in correcting for change of atmospheric pressure or to overheating.

The curves given above not only render the supposition of overheating improbable, but also indicate the cause of the large and variable values of the elevation constant

* *Proc. Roy. Soc. Edin.*, 25, 960, 1905.
† *Zeit. für phys. Chemie*, 40, 185 (1902). ‡ *Ibid.* § *Ibid.*

obtained above. The fact that in the case of each salt the curves run parallel, and the difference in the elevation which they give for any given concentration is thus independent of the concentration of the solution, makes it probable that the source of error lay in the observation affecting all the elevations, *i.e.* that of the boiling point of water. If I am correct in thinking that the above large values are due to error in the

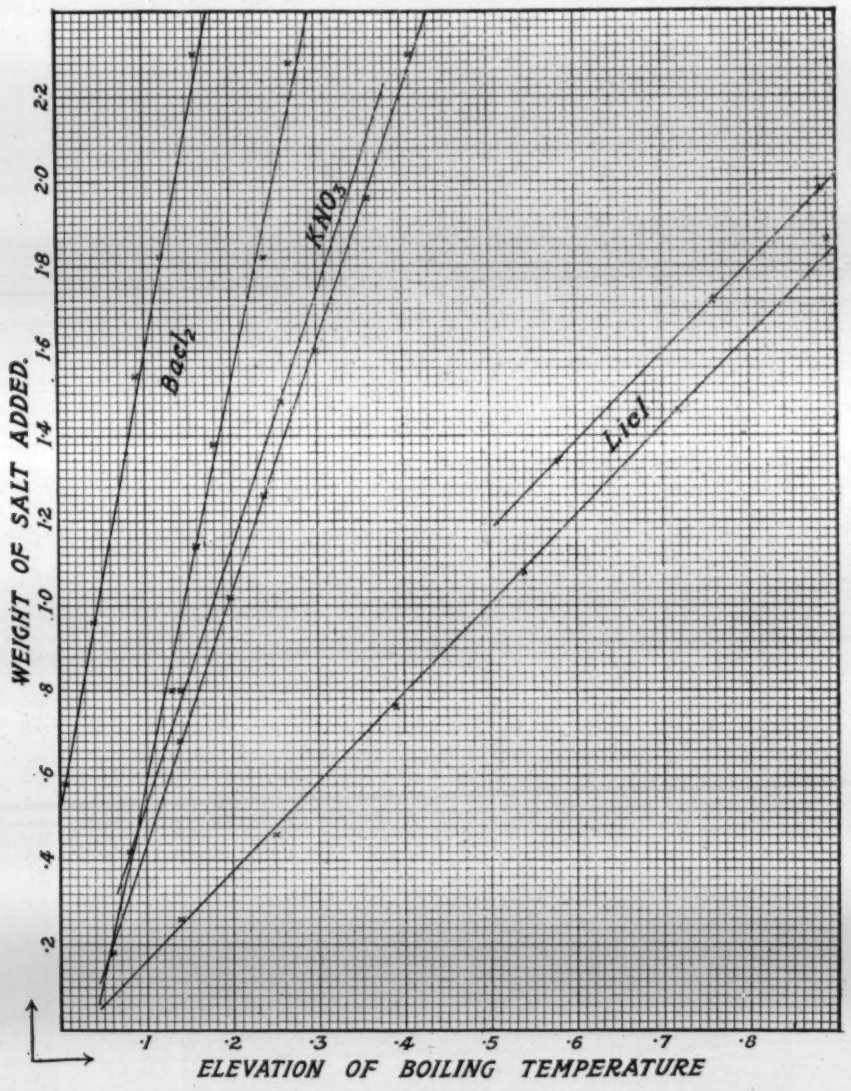

FIG. 2.

determination of the boiling point of water, then in a series of determinations in which increasing amounts of salt are added to the same water, the elevations observed would all be affected by the same error, which would, in general, be different for different series of experiments. If so, and if series of observations be made for the same salt, and if observed elevation be plotted against weight of salt added for several series, we might expect to obtain parallel, but in general not coincident, curves.

To find out whether or not the determination of the boiling point of water is more liable to be in error than that of a solution, I applied heat successively of different

strengths, and found, in the case of pure water, that a steady boiling temperature could be raised, or lowered, by increasing or decreasing the strength of the source

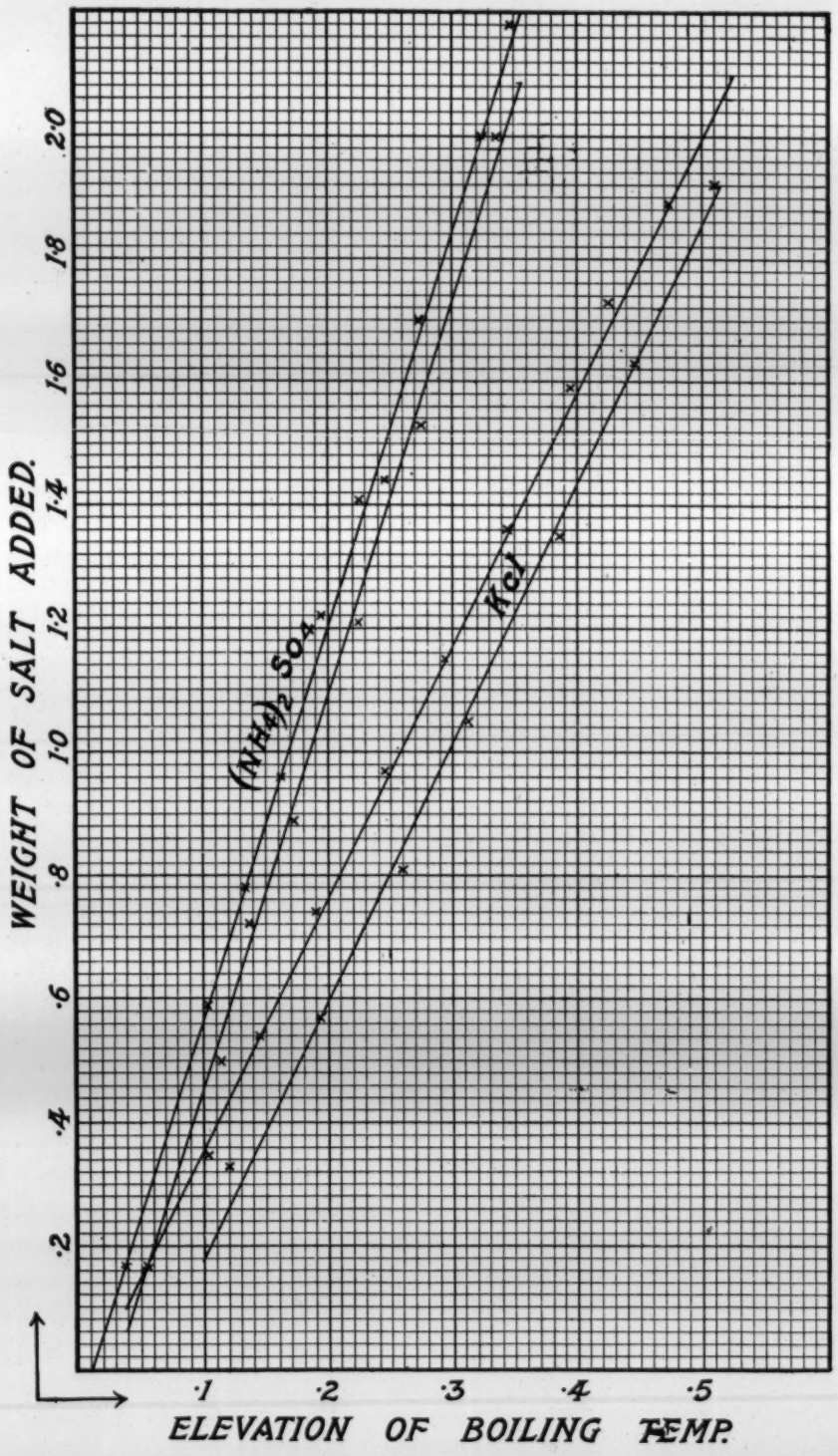

FIG. 3.

of heat, within the range of several hundredths of a degree; while a solution, on the other hand, was found to take up a definite boiling temperature which was independent of small changes in the strength of the source of heat so long as ebullition

was maintained. The above curves, therefore, show that the differences in observed elevation of boiling points were due for the most part to unavoidable inaccuracy in

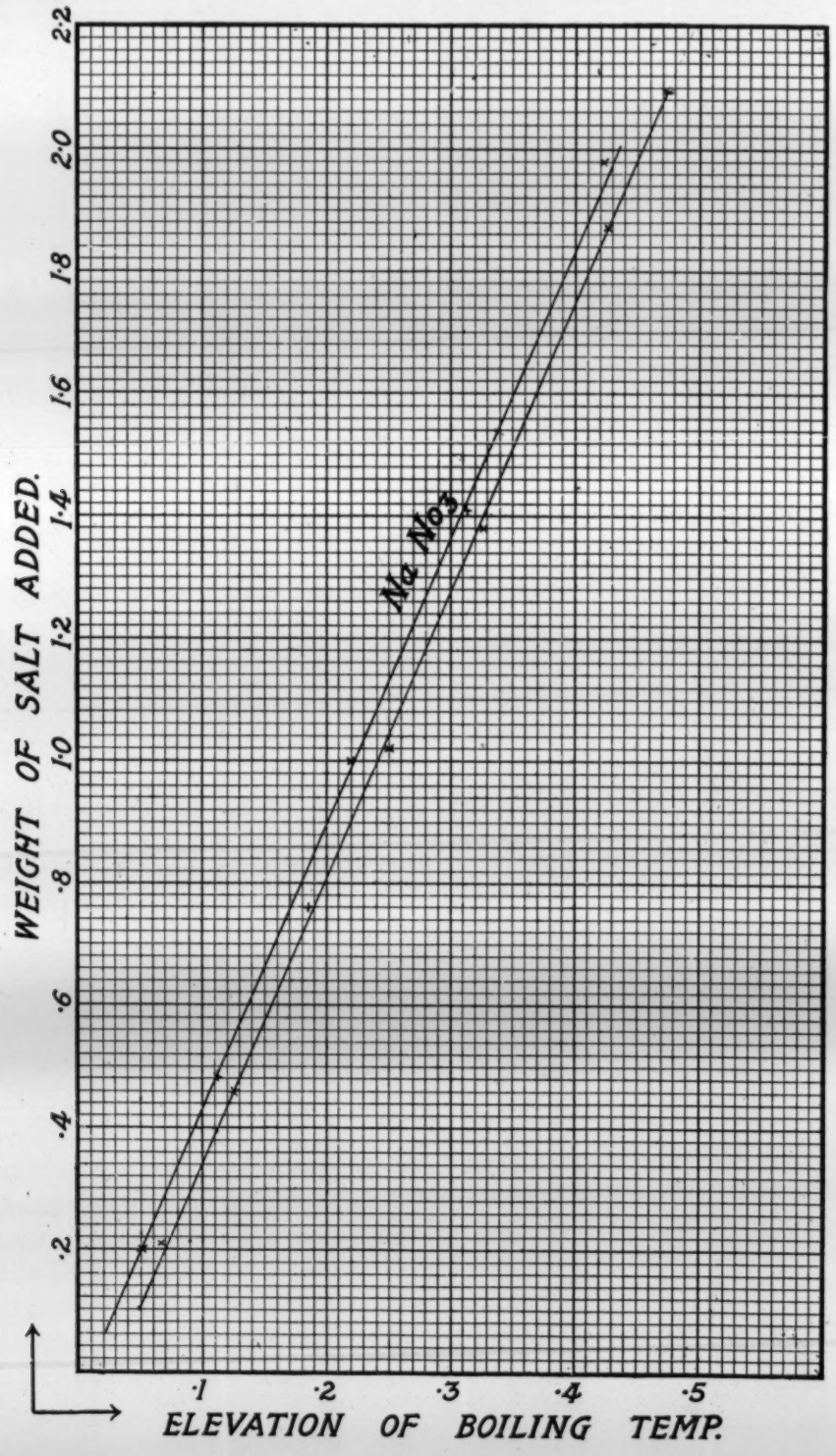

FIG. 4.

determining the boiling point of water, and only to a slight extent to error in determining the boiling points of solutions. It would follow that values of the elevation of the boiling point of a solution above that of water may be affected by a large

error, while those based upon the observed elevation of the boiling point of a stronger solution above that of a weaker solution will be independent of the possibly large error which may affect the determination of the boiling point of water.

Accordingly, in computing the values of the elevation constant, I have used the following expression—

$$C = \frac{m.W.\Delta E}{[1+(n-1)a]\Delta w},$$

where m, W, n and a are as before, and ΔE is the increment in boiling-point elevation corresponding to the addition of Δw grammes of salt to a solution.

The ratio $\frac{\Delta E}{\Delta w}$ was found as follows :—

Let OW and OE be axes of weight of salt added and elevation of boiling temperature respectively. Let LR, the curve for any series of observations, found as seen above to be for dilute solutions approximately a straight line, be produced to meet the axis in P. Through any near points Q and R on this curve draw parallels to the axes.

$$\frac{\Delta E}{\Delta w} = \frac{QS}{RS} = \frac{PT}{TR} = \frac{E-OP}{w}.$$

$$\text{Hence } C = \frac{E-OP}{w}\left(\frac{mW}{1+n-1a}\right).$$

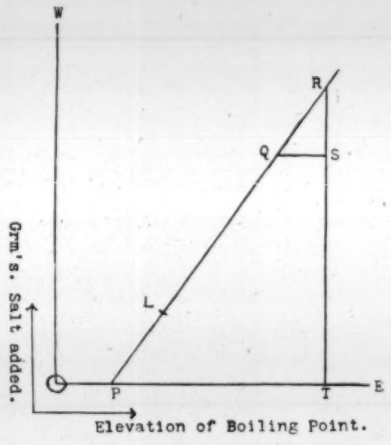

FIG. 5.

PART II.

(1) THE BOILING-POINT ELEVATION CONSTANT.

We now come to the determination of the boiling-point elevation constant for which observations on dilute solutions only have been used.

In the computations given below, I have used the formula given above.

The conductivity values used in the calculations are my own (see Part III.), except those for KNO_3, for which KRANNHALS' values have been used.

From these tables it will be seen that the values of the elevation constant obtained for the various salts lie about 520, some being greater, some less.

The value obtained, 519·6, is the mean of the means for the several series of observations the results of which are given below. I have given several other series of determinations in *Proc. Roy. Soc. Edin.*, 25, 960, 1905. From the first series of each salt there given the mean of the mean values for the several series is 519·5.

The experimental value of the elevation constant, as I have obtained it, is consequently very approximately the theoretical value.

[TABLES.

AMMONIUM CHLORIDE.

Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·141	·128	·844	520
·412	·363	·704	522
·793	·573	·653	518
·825	·760	·650	520
1·055	·892	·630	523
1·255	1·076	·620	519
1·531	1·329	·606	523

AMMONIUM SULPHATE.

Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·048	·039	·672	522
·092	·071	·614	520
·168	·103	·562	523
·236	·138	·536	521
·294	·163	·520	523
·374	·191	·496	518
·436	·236	·483	521
·518	·275	·458	524
·612	·321	·442	521

CADMIUM IODIDE.

Grm. eqs. per Litre.	Elevation of Boiling Point	Ionization Co-eff.	Elevation Constant.
·415	·169	·167	520
·639	·218	·146	516
1·048	·286	·119	519
1·210	·354	·115	521
1·308	·436	·113	519

POTASSIUM NITRATE.

Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·041	·063	·665	519
·089	·112	·657	511
·139	·160	·642	514
·187	·206	·629	521
·244	·252	·616	518
·301	·292	·611	516
·364	·348	·608	516
·431	·403	·605	516

CADMIUM CHLORIDE.

Grms. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·330	·129	·251	517
1·512	·484	·132	520

CAESIUM NITRATE.

Grms. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·312	·310	·706	514
·758	·675	·618	520
1·175	1·010	·580	525
1·418	1·310	·550	519

(2) MOLECULAR WEIGHT CALCULATIONS.

Owing to the fact that boiling point elevation determinations have been affected by the large error pointed out in the determination of the boiling point of water, it has not been possible with water as solvent to make other than rough determinations of molecular weights, and the error in the determination of the boiling point of water being variable from experiment to experiment, the determinations made by different experimenters have varied by as much as 20 per cent.* The error involved would frequently have been greater had not one error helped to counterbalance another. That is, the assumption of total ionization, when the latter was only from 70 to 80

* *Ber. der Chem. Ges.*, 31, 471 (1898); *Practical Methods for determining Molecular Weights*, BILTZ, translated by JONES and KING, p. 189 (1899); *Zeit. für Anorg. Chemie*, 17, pp. 435 and 450 (1898); SAKURAI, *Journal of Chem. Soc.*, 61, 989; WALKER and LUMSDEN, *Journal of Chem. Soc.*, 73, 509 (1898).

or 90 per cent., not unfrequently diminished the error resulting from an inaccurate determination of the boiling point of water.

For all the salts the boiling-point data given in the following tables are my own, but for KCl, KBr, $NaNO_3$, KNO_3, and NaCl the ionization coefficients are from conductivity values given by KRANNHALS. For these I considered it sufficient to calculate the ionization coefficients to two places of decimals, as KRANNHALS only claims an accuracy of from 2 to 3 per cent. error limit.

For the remainder of the salts considered the ionization coefficients have been obtained from conductivity data determined by myself, which are given in Part III. of this paper. For these I have usually calculated the ionization coefficients to three places of decimals.

The following tables contain molecular weight computations which have been made by the use of the formula

$$m = \frac{C(1 + \overline{n-1}\alpha)\Delta w}{W\,\Delta E}.$$

SODIUM CHLORIDE.

Grms. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight.
·2070	·48	·080	·096	·79	59·8
·4294	·91	·162	·169	·76	58·0
·6143	1·23	·218	·228	·70	57·5
·8314	1·66	·294	·294	·68	57·4
1·0277	2·01	·356	·356	·67	57·3
1·2160	2·38	·404	·421	·66	57·4
1·5870	2·98	·528	·541	·65	57·7
2 0284	3·88	·634	·680	·65	58·4
2·5044	4·80	·856	·826	·64	57·9
2·9744	5·67	1·004	·986	·64	57·7
3·4182	6·47	1·148	1·144	·63	57·6

Mean molecular weight found. 57·9.
* International value, . 58·9.

SODIUM NITRATE.

Grms. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight
·2054	·36	·042	·053	·87	86
·4860	·87	·105	·111	·82	87
1·0198	1·81	·218	·220	·76	87
1·4880	2·50	·302	·312	·70	86
1·9852	3·60	·435	·420	·65	85
2·5216	4·80	·578	·530	·62	82
3·0242	5·54	·667	·632	·59	80
3·5682	6·58	·744	·700	·54	83

Mean molecular weight found, 84·4.
* International value, . . 85·09.

AMMONIUM SULPHATE.

Grms. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight.
·1750	·352	·048	·039	·670	135·4
·3140	·630	·092	·075	·610	133·2
·7306	1·553	·236	·150	·536	131·7
·9590	1 902	·294	·177	·518	132·6
1·2245	2·417	·374	·215	·496	132·5
1·4358	2·82	·436	·250	·478	132·0
1·7120	3·34	·518	·299	·456	130·1
2·0126	3·91	·612	·345	·438	131·8

Mean molecular weight found, 132·4.
* International value, . 132·20.

POTASSIUM BROMIDE.

Grm. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight.
·4250	·85	·088	·112	·796	121
·6854	1·36	·140	·161	·774	123
·8813	1·75	·170	·198	·758	120
1·0293	2·03	·208	·223	·744	118
1·2945	2·55	·260	·252	·732	118
1·5705	3·07	·312	·312	·720	116
1·9564	3·88	·396	·374	·706	115
2·3074	4·45	·456	·435	·692	114

Mean molecular weight found, 118·1.
International value, . . 119·11.

* International atomic weights, 1904.

Potassium Nitrate.

Grms. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight.
·2118	·42	·041	·063	·665	101
·445	·89	·089	·112	·657	104
·6986	1·39	·139	·160	·642	102
·9318	1·85	·187	·206	·629	99·4
1·2126	2·39	·244	·252	·616	100
1·5044	2·95	·301	·292	·611	103
1·8366	3·57	·364	·348	·608	103
2·1876	4·23	·431	·403	·605	101

Mean molecular weight found, 101·2.
International value, . 101·19.

Potassium Chloride.

Grms. Salt added to 50 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Molecular Weight.
·1754	·35	·048	·054	·89	73
·3546	·71	·124	·101	·88	73·3
·5424	1·08	·144	·146	·87	76
·7426	1·47	·202	·190	·85	76
·9740	1·93	·266	·247	·83	76
1·1520	2·26	·316	·291	·81	76
1·3684	2·69	·370	·343	·79	76
1·5924	3·11	·428	·394	·77	74
1·7278	3·37	·466	·425	·76	74
1·8918	3·68	·508	·471	·75	74

Mean molecular weight found, 74·83.
International value, 74·60.

Cadmium Iodide.

First Series.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·6600	·077	4·296	·232	·217	362·0
1·1440	·131	7·22	·413	·176	355·8
1·8258	·191	11·05	·655	·145	370·1
2·3248	·243	13·65	·855	·130	358·2
2·8564	·308	16·27	1·055	·119	360·0
3·7138	·381	20·17	1·350	·112	375·2
4·4524	·461	23·24	1·580	·107	370·8

Mean molecular weight found, 364·6.
* International value, . 366·1.

Cadmium Iodide.

Second Series.

Grms. Salt added to 50 c.c Solvent.	Elevation of Boiling Point.	Per cent. Composition	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
1·228	·169	7·68	·445	·167	357·7
1·7636	·218	10·70	·639	·146	361·8
2·3870	·286	14·04	1·048	·119	369·2
2·9670	·354	16·80	1·210	·115	365·6
3·6850	·436	20·05	1·308	·113	367·2
4·3828	·517	22·97	1·563	·107	364·8
5·0616	·577	26·12	1·825	·101	372·9
5·8536	·682	28·41	2·021	·096	361·9

Mean molecular weight found, 365·1.
International value, . 366·1.

Sodium Bromide.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre	Ionization Co-eff.	Molecular Weight.
·9508	·405	1·88	·199	·734	103·4
1·4200	·544	2·78	·294	·704	103·3
2·3200	·699	4·47	·477	·644	103·0
3·2574	·781	6·16	·656	·610	101·0
4·3470	·938	8·08	·870	·571	98·0

Mean molecular weight found, 101·74.
* International value, . 103·01.

Ammonium Sulphate.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·7806	·156	1·553	·236	·536	131·4
·9590	·177	1·902	·294	·518	132·0
1·2245	·215	2·417	·374	·496	132·5
1·4358	·250	2·82	·436	·478	130·1
2·0126	·345	3·91	·612	·438	132·0

Mean molecular weight found, 131·6.
International value, . 132·2.

* International atomic weights, 1904.

LITHIUM NITRATE.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·1820	·103	·366	·041	·686	68·7
·5462	·193	1·09	·132	·648	68·0
·9032	·278	1·793	·284	·598	68·3
1·6328	·441	3·19	·433	·562	68·4
3·3990	·830	6·43	·921	·494	68·8

Mean molecular weight found, 68·4.
* International value, . 69·07.

AMMONIUM BROMIDE.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·4134	·275	2·735	·368	·754	100·1
·842	·542	5·427	·749	·688	96·3

Mean molecular weight found, 98·2.
International value, . 98·03.

POTASSIUM IODIDE.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·7186	·351	4·66	·280	·768	173·1
2·5382	1·010	14·44	·962	·600	160·9

Mean molecular weight found, 167.
International value, . 166·00.

AMMONIUM CHLORIDE.

Grms. Salt added to 15 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular. Weight
·1260	·128	·850	·141	·844	53·4
·3422	·363	2·26	·412	·704	53·8
·6552	·573	4·26	·793	·653	54·1
·7604	·760	4·94	·825	·650	53·6
·8730	·892	5·61	1·055	·630	51·9
1·0476	1·076	6·65	1·255	·620	53·5
1·2812	1·329	8·01	1·531	·606	54·5
1·5620	1·662	9·60	1·852	·598	52·2

Mean molecular weight found, 53·5.
International value, . 53·52.

POTASSIUM BROMIDE.

Grms. Salt added to 50 c.c. Solvent.	Elevation of Boiling Point.	Per cent. Composition.	Grm. eqs. per Litre.	Ionization Co-eff.	Molecular Weight.
·4254	·120	·85	·092	·796	122·7
·6854	·173	1·36	·132	·774	122·7
·8813	·212	1·75	·164	·758	120·6
1·0293	·238	2·03	·204	·774	118·4
1·2945	·262	2·55	·256	·732	118·0
1·5705	·324	3·07	·308	·730	116·6
1·9564	·386	3·88	·392	·706	116·2
2·3074	·451	4·45	·472	·692	114·7

Mean molecular weight found, 118·73.
International value, . 119·11.

In the tables given above, whether these have been molecular weight calculations or a determination of the value of the boiling-point elevation constant, the results are in close agreement with the results of other experimental methods and with theory.

It will therefore be seen that, when moderately dilute or dilute solutions are under investigation, the method which has been adopted gives greatly increased accuracy to results whether these are molecular-weight determinations by the boiling-point method or values of the elevation of the boiling-point constant.

It may also be noted that, as the manner in which the ionization coefficients were obtained and the formula used in calculating values of the elevation constant, were based on the dissociation theory, the latter has been put to a somewhat severe test, and as the results agree so fully with theory, it has been entirely favourable.

* International atomic weights, 1904.

PART III.

Conductivity Observations at High Temperature. An Improved Method of obtaining these.

Those who have given conductivity values at high temperatures, say, from 99° to 100° Centigrade, have done so only for dilute solutions, with perhaps the single exception of NaCl, for which Lyle and Hosking * have given values up to a concentration of four gramme equivalents per litre, and, speaking generally, observations have only been made to a dilution of about one-thousandth normal.

I resolved to test whether this dilution was satisfactory for the purpose of determining the conductivity at infinite dilution, and also to obtain conductivity data at very much higher concentrations than those used by other observers, with an object in view which will be apparent in Part IV. of this paper.

To do so I designed two electrolytic cells, one for dilute, the other for concentrated solutions, suitable for direct heating. The conductivity observations I have made have been at a temperature near the boiling point of the solvent, with the conditions as nearly as possible the same as those under which the observations of boiling-point elevation were made. Rough sketches of the cells are given in figs. 6 and 7.

Fig. 6 represents a section of the cell for dilute solutions, with a range, say, from normal to one- or two-thousandths normal. B is the outer or boiling tube. The tube D contains, when the apparatus is in use, a condensing tube of the Beckmann pattern. C is an inner tube fitted into B by means of a rubber stopper F, through a hole which it fits tightly. The electrodes E and the thermometer T reading to tenths from 97° to 110° Centigrade, and having its scale entirely above A′, are placed in the inner tube C. This tube is perforated at a and a'. The one opening allowing the solution placed in the boiling tube B to pass into or out of the inner tube, the other allowing the vapour formed in C to pass over to the condensing tube D. The glass tubes b and b', by means of which the cell is connected with the bridge, pass through a vulcanite top A′, in which they are cemented, and through a rubber stopper F′ into the inner tube. The thermometer does so also, but is not cemented into the vulcanite top. A little side tube G was attached and fitted with a rubber stopper for increasing the concentration of solutions by the direct addition of salt.

The tube designed for strong solutions with which conductivities may be measured from half-normal solutions to any degree of normality desired, is represented in fig. 7. AA′ is the boiling tube, which has two limbs, with short tubes D and D′ attached to hold small condensers of the Beckmann pattern. The tubes have each a short resistance portion, as represented. E and E′ are the electrodes not fitting tightly the tubes in which they are placed. The glass connection tubes F and F′ pass through rubber stoppers C and C′, and the vulcanite tops a and a', into which they are fixed by

* *Phil. Mag.* (6), 3, 487, 1902.

means of a screw arrangement at B. The screw is so constructed as to press against a little cushion of rubber, which presses against the glass tube, and may be made to

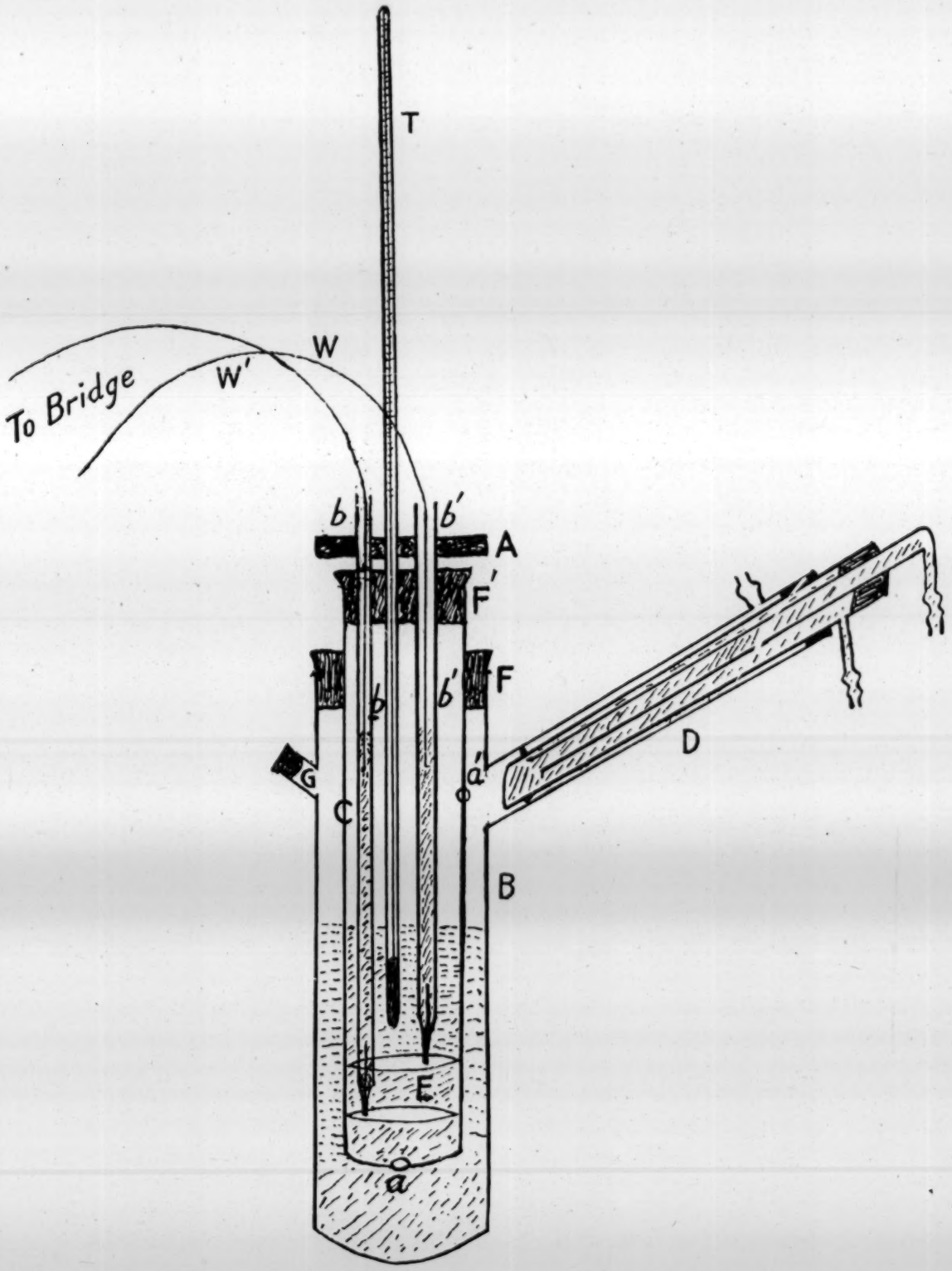

FIG. 6.

do so as firmly as desired. The tubes F and F′ had shoulders below the stopper C and C′, to prevent the stoppers from sliding down. The wires to the bridge are, as in

the tube for dilute solutions, already described. The cell tubes were all made of Jena

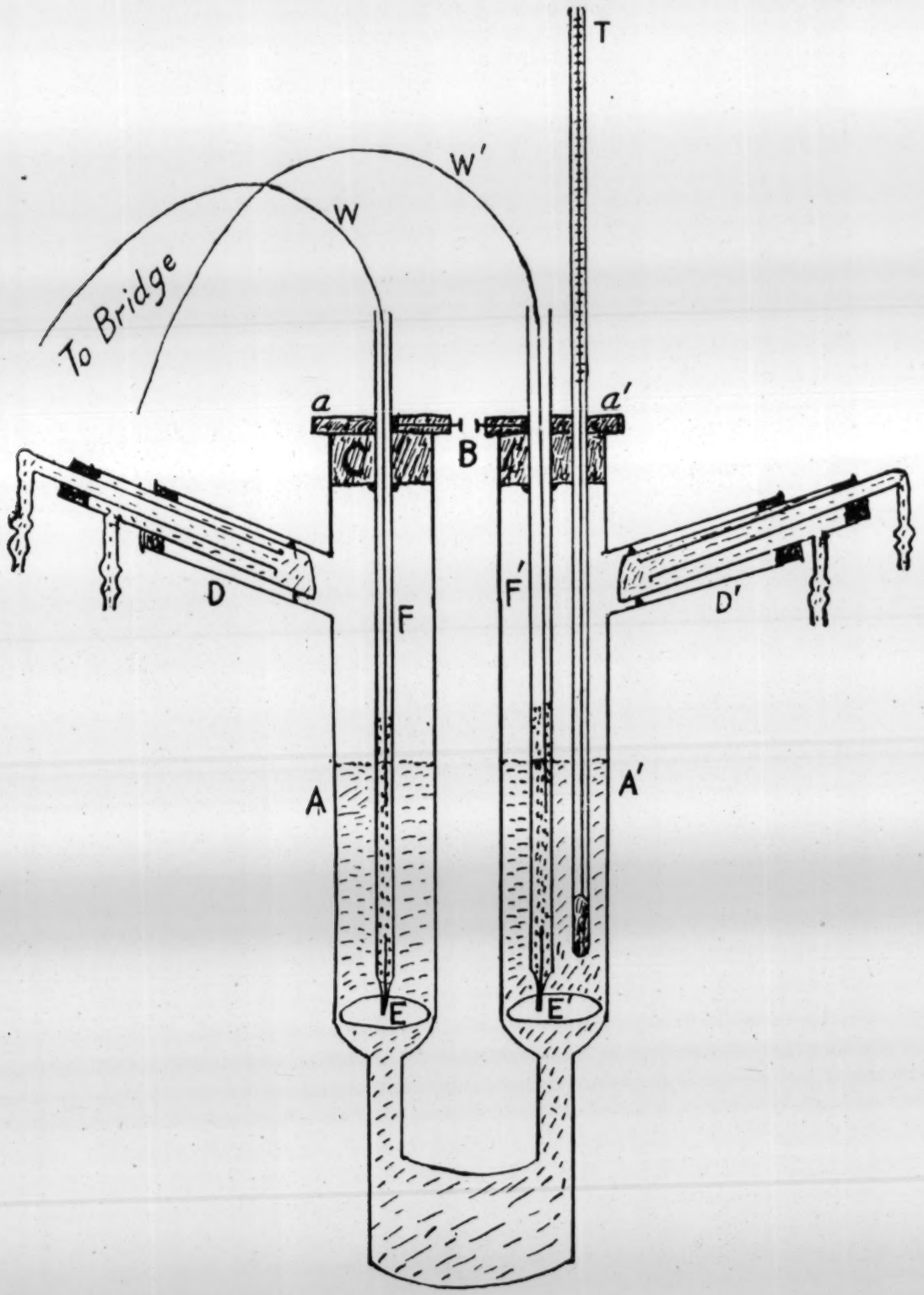

FIG. 7.

glass; that is, the boiling tube, the inner one, and those making mercurial connection to the electrodes, which were of thick platinum foil.

The pure water used when conductivity experiments were made was obtained by

using distilled water, which was redistilled from a flask containing a little potassium bichromate and sulphuric acid into one containing a small quantity of barium hydrate, thence to a condenser with Jena glass worm to a Jena glass flask for its reception. The water was kept in a Jena glass bottle. By the method above described for water purification, a water was obtained of specific conductivity of $\cdot 23 \times 10^{-6}$, Kohlrausch units cm.$^{-1}$ ohm^{-1}. During the time the experiments were being made, the results of which are given, a register of water purity was kept, its electrical resistance being frequently measured as a safeguard.

In conductivity work a Wheatstone bridge, after the Kohlrausch pattern for electrolytes, with telephone as current indicator, was used. The bridge wire was calibrated by the Strouhal and Barus method,* and the electrodes of the resistance tubes were platinised.†

Observations were made by the method already given (page 196), to determine the amount of vapour present in the tube during an experiment, and the change in concentration allowed for.

It was assumed that in finding values of $\frac{\mu_v}{\mu_\infty}$ for the boiling point, the ratio of the dilutions at 100° of two solutions might be taken equal to the corresponding ratio at 15°. Experiments were made to determine the error involved, which was found to be no more than ·03 per cent. even for a sevenfold normal solution.

When making up solutions, a table of solubilities was consulted, to ascertain the composition of a solution saturated at 15° Centigrade. Five hundred or a thousand cubic centimetres of solution were made up of this concentration, which was done by weighing so many gramme equivalents of salt according to the concentration desired, placing it in a flask, dissolving in water, and bringing the solution to the standard volume 500 or 1000 cubic centimetres at 15° Centigrade. The various dilutions were obtained from this by the addition of solvent to a measured number of cubic centimetres of solution. For this 20, 25, and 50 cubic-centimetre pipettes were used, and 100, 200, 300, and 500 cubic-centimetre flasks, all of which had been tested at 'Charlottenburg.' In addition I tested the pipettes myself. One of these dilutions, usually the tenth normal, was tested quantitatively as a safeguard against error.

It will be noted that I have found conductivity values at very high concentrations, indeed in some instances beyond the solubility at 15° Centigrade. These were obtained for a reason which will appear in Part IV. of this paper, as follows: I desired the conductivity at a certain concentration beyond the solubility at 15°, but within the solubility at 100° Centigrade. In each case I calculated the amount of salt required to the amount of solvent to be used in the experiment, and placed it in the boiling resistance tube, adding the solvent afterwards. This was then heated to the desired temperature, and the reading taken. Several such experiments were made for various salts; the results so obtained are marked with an asterisk.

* *Wied. Annal.*, 10, 326 (1880).

† *Zeit. phys. Chemie*, 21, 297.

The method adopted gave every satisfaction, the results being obtained easily without any undue waste of time.

The following tables give ionization coefficients and equivalent conductivities obtained by the above methods. In these μ_v represents equivalent conductivity at the dilution v, and μ_∞ that at infinite dilution, v being equal to the number of litres to the gramme equivalent.

Ammonium Chloride.			Lithium Chloride.			Lithium Nitrate.		
Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.
·200	·431	1639	·100	·149	463	·166	·260	726
·250	·495	1882	·111	·161	502	·200	·268	746
·333	·532	2027	·125	·196	609	·250	·308	845
·500	·583	2220	·200	·313	978	·500	·411	1146
1	·629	2356	·500	·476	1471	1	·486	1353
2	·681	2592 2595	1	·558	1726 1726	2	·546	1515 1521
4	·751	2860	2	·628	1942	4	·609	1695
10	·808	3077	4	·695	2150	10	·667	1857
20	·857	3265	8	·739	2292	20	·694	1933
40	·895	3417	16	·797	2474	40	·725	2020
80	·913	3500	40	·834	2589	80	·744	2072
200	·960	3656	100	·854	2650	300	·803	2237
1000		3820	1000		3101	1000	·912	2540
2000		3806				2000		2783

Ammonium Sulphate.			Potassium Iodide.			Ammonium Iodide.		
Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.
·118*	·167	759	·233*	·459	1800	·2004*	·303	1199
·138*	·198	904	·282*	·496	1943	·227*	·331	1309
·16*	·205	941	·5	·599	2349	·271*	·370	1466
·25	·250	1208	1	·645	2546 2530	·285*	·394	1558
·5	·307	1407	2	·733	2875	·5	·588	2221
1	·373	1807 1807	4	·796	3118	1	·650	2446
2	·465	2130	8	·844	3306	2	·728	2736
5	·548	2509	16	·882	3457	4	·798	3014
10	·609	2787	80	·937	3671	8	·852	3219
20	·701	3291	300	·950	3724	16	·875	3305
50	·745	3743	1000		3990	32	·912	3446
500	·868	4070	2000		3917	100	·966	3648
1000		4583				1000		3775
2000		4574						

Sodium Bromide.		
Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.
·250	·380	1444
·500	·452	1811
1	·555	2085 / 2097
2	645	2426
4	·719	2734
10	·761	2873
20	·801	3026
3000		3774

Ammonium Bromide.			Lithium Bromide.			Cadmium Iodide.		
Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.	Litres per Grm. eq.	μ_v/μ_∞	Eq. Conductivity.
·184*	·413	1540	·100	·151	470	·312*	·081	269
·264*	·477	1775	·143	·238	716	·500	·098	324
·333*	·524	2083	·200	·317	986	1	·122	406
·5	·599	2255	·500	·494	1534	2	·157	500
1	·655	2438	1	·575	1786	5	·227	755
2	·721	2683	2	·666	2068	10	·296	984
4	·786	2926	5	·737	2289	1000		3317
10	·851	3168	10	·776	2409			
20	·906	3373	1000		3102			
40	·936	3483						
1000		3721						

Duplicate readings were taken occasionally, for the normal or half-normal solution, one with each tube: the one thus acted as a check on the other. The duplicate values as a rule were approximately the same: in some instances they were the same. The conductivity value at two-thousandth was sometimes almost the same as that at one-thousandth normal. In one or two instances it was considerably more.

The duplications at normal or half-normal and infinity indicate an error limit for the former of $\frac{1}{2}$ per cent., and for the latter of $2\frac{1}{2}$ per cent. It has been pointed out on page 219 that very great accuracy is not required for my purpose in the ionization coefficients.

The results given above have been represented graphically by the aid of the following curves: μ_v/μ_∞ has been plotted (1st) against gramme equivalents per litre, (2nd) against grammes of salt added to a constant amount of solvent, and (3rd) against percentage composition. If these be spoken of as curves 1, 2, and 3, it will be seen that the curves No. 2 are very much straighter than curves No. 1, and that those of No. 3 are still straighter.

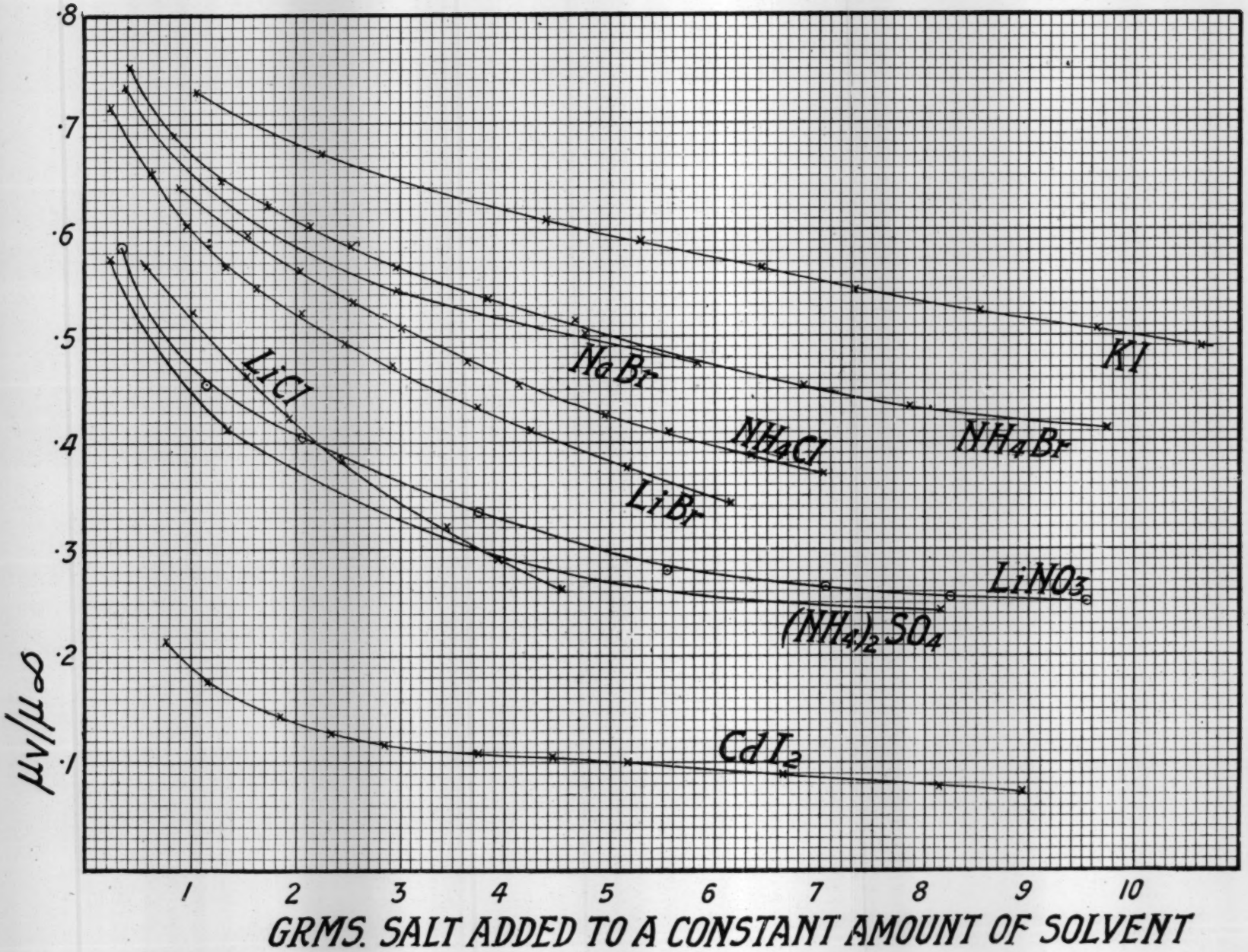
·8
·7
·6
·5
·4
·3
·2
·1
μv/μ∞
LiCl
NaBr
KI
NH4Cl
NH4Br
LiBr
LiNO3
(NH4)2SO4
CdI2
1
2
3
4
5
6
7
8
9
10
GRMS. SALT ADDED TO A CONSTANT AMOUNT OF SOLVENT

FIG. 8.

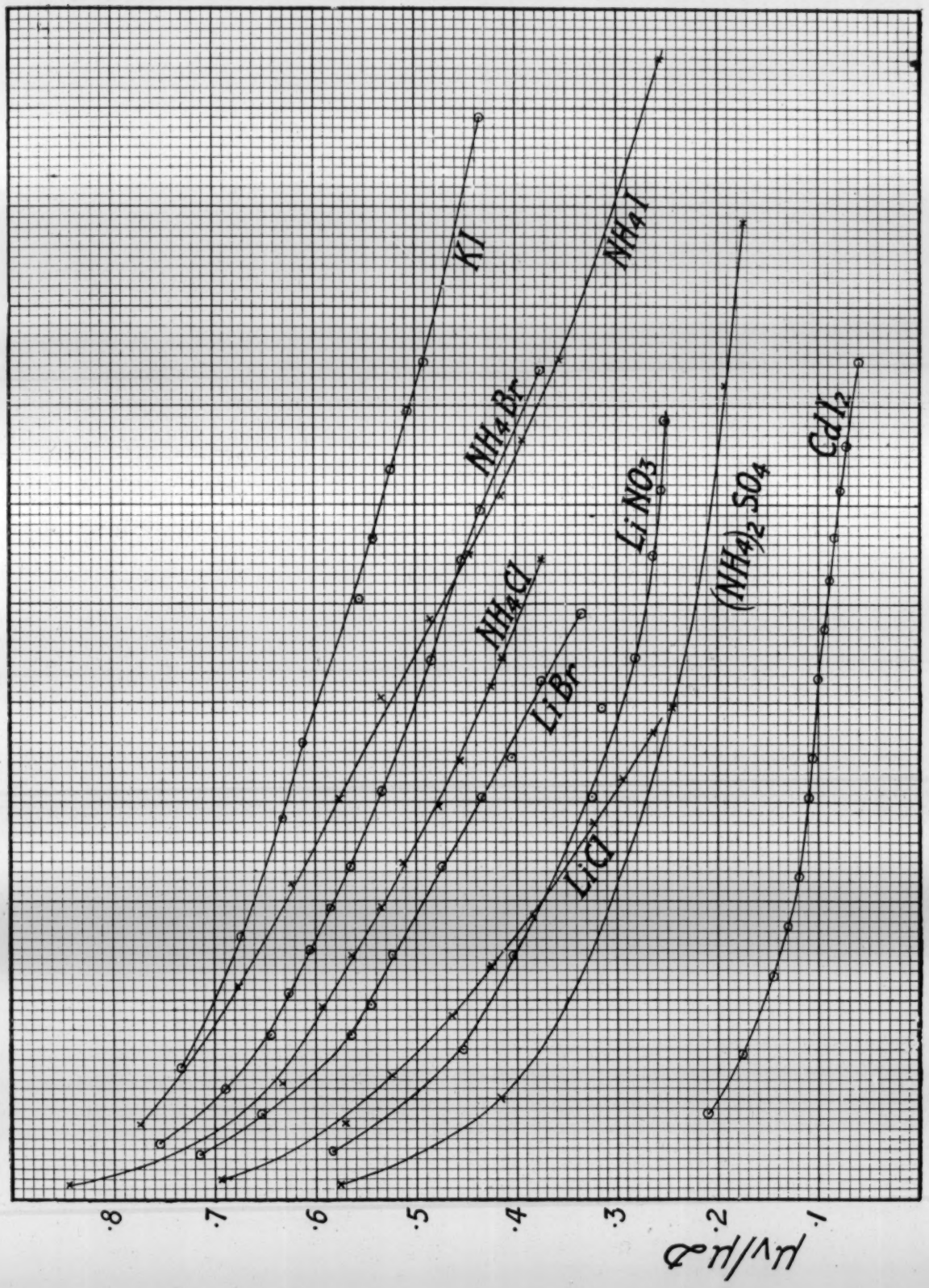
KI
NH4I
NH4Br
NH4Cl
LiNO3
(NH4)2SO4
CdI2
LiBr
LiCl
μv/μ∞
.8
.7
.6
.5
.4
.3
.2
.1
5
10
15
20
25
30
35
40
45
50
55
PER CENT. COMPOSITION

FIG. 9.

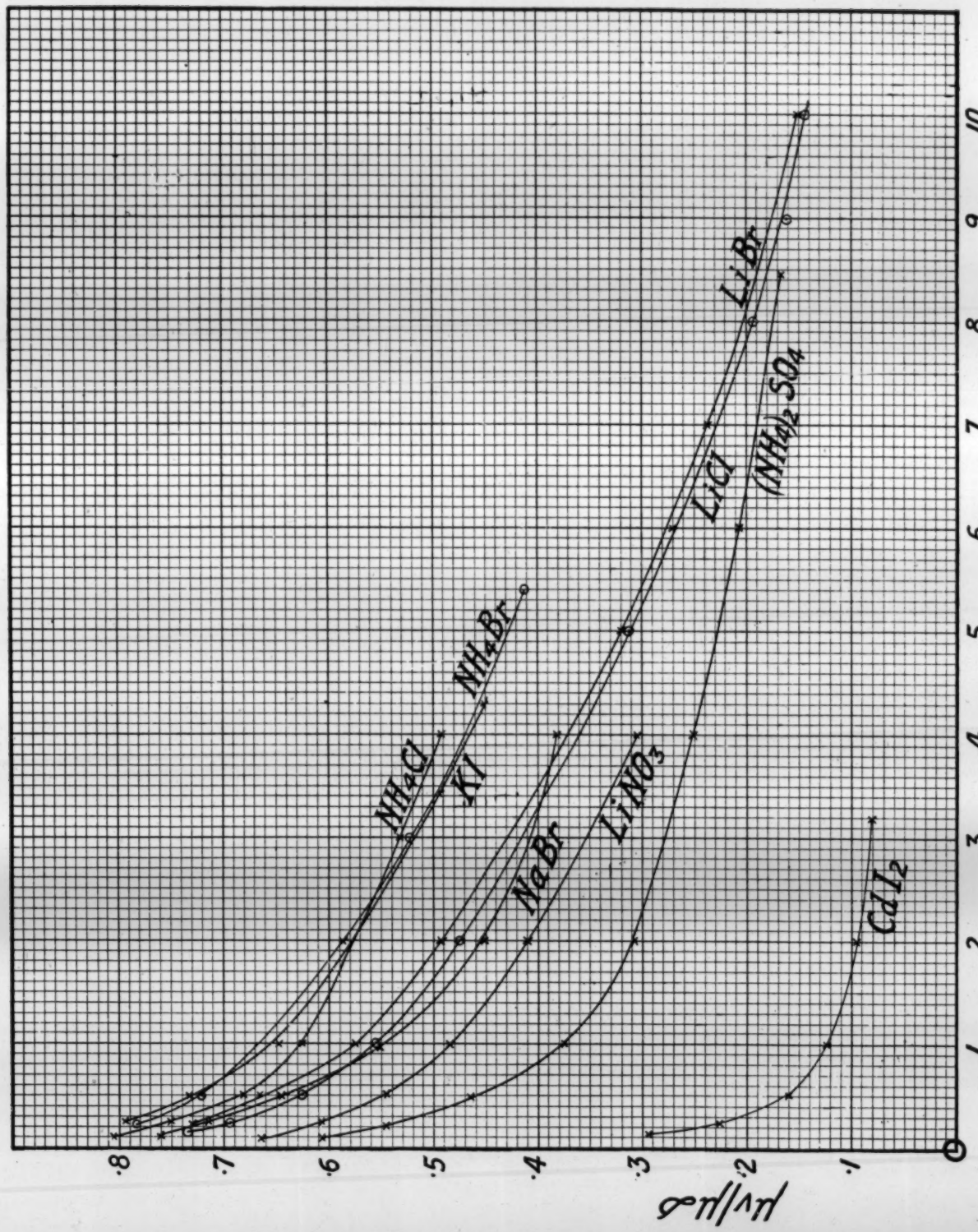
LiCl
LiBr
(NH4)2SO4
NH4Cl
NH4Br
KI
NaBr
LiNO3
CdI2
μv/μ∞
GRM. EQS. PER LITRE
0
1
2
3
4
5
6
7
8
9
10
·1
·2
·3
·4
·5
·6
·7
·8

Fig. 10.

CdI2
LiNO3
LiBr
(NH4)2SO4
NaBr
NH4Cl
LiCl
KI
NH4I
NH4Br
1
2
3
4
5
6
7
8
9
10
LITRES PER GRM. EQUIVALENT
1000
2000
3000
CONDUCTIVITY PER GRM. EQUIVALENT

FIG. 11.

These results are interesting from the standpoint of reading values from curves.*

I have also plotted equivalent conductivity against the number of litres to the gramme equivalent (fig. 11).

This was done that the curves obtained in this way might be compared with the corresponding curves obtained from KRANNHALS' conductivity values. The curves obtained in this manner from his data and mine were quite similar in form.

JONES and WEST† have pointed out that the dissociation of a salt in a solution of known concentration decreases as the temperature of the solution is raised from 0° Centigrade to 35° Centigrade. As they have determined the ionization of some salts at temperatures varying from 0° Centigrade to 35° Centigrade, for which I have determined it at 99·4° Centigrade, I have been able to make a comparison between the ionizations at the lower temperatures at which they worked and those at 99·4° Centigrade. In every instance the ionization at the higher temperature was found to be smaller than that at the lower temperature.

The following is an illustration taken from the ionizations of ammonium chloride from JONES and WEST's data and mine.

Litres per Gramme eq.	Ionization at 0° C. JONES and WEST.	Ionization at 35° C. JONES and WEST.	Ionization at 99·4° C. Mine.
1			·629
2	·840	·777	·681
4			·751
8	·884	·854	
10			·808
16	·908	·886	
20			·857
32	·938	·919	
40			·895
80			·913
128	·976	·965	
200			·960
512	·994	·989	
1000			1·000
1024	1·000	1·000	

The figures given above show that the effect of increase of temperature on ionization is to diminish ionization for a solution of given concentration, and that the diminution of ionization increases with the concentration of the solution, and becomes zero at zero concentration, as one would expect, the ionization coefficient at any temperature having become unity. Consequently, were the above results represented graphically by curves obtained by plotting litres per gramme equivalent against the ionization coefficients for several temperatures, the temperature being constant for the same curve,

* In a paper read recently at the Royal Society, Edinburgh, Dr GIBSON has pointed out a somewhat similar result.

† *Am. Chem. Journ.*, vol. xxxiv., No. 4, 373 (1905).

the curves obtained thus would meet at infinite dilution and diverge with increase of concentration. This result is in accordance with the conclusion of former observers.

PART IV.

Concentrated Solutions.

We come now to study solutions, reaching as high a concentration as 7 or 8 gramme equivalents per litre.

In the following pages the results are given of calculations which have been made of the elevation constant over a wide range of concentration.

The formula employed was—

$$C = \frac{m.W.\Delta E}{(1 + n - 1\alpha)\Delta w},$$

where C is the boiling-point elevation constant—

m = molecular weight of salt added.
W = weight of solvent used in grammes.
ΔE = increment of elevation of boiling point on addition of salt to a solution.
Δw = increment of salt added in grammes.
α = ionization coefficient assumed equal to the ratio of equivalent conductivity at the concentration to that at infinite dilution.
n = the number of free ions into which a molecule dissociates.

A boiling tube for 15 cubic centimetres of solvent was used, consequently concentrated solutions were quickly obtained. In consequence we have only a very few observations for dilute solutions. It was impossible therefore as a rule to draw the curves with grammes of salt added as ordinates, and elevation of boiling point as abscissæ, so accurately in the neighbourhood of the origin as when dilute solutions were specially under consideration. In consequence a smaller degree of accuracy must be expected in values obtained for the elevation constant for the dilute solutions than when the latter were being dealt with specially. The error involved in determining the increment of the elevation, although it creates a somewhat large percentage error for the dilute solutions, is usually under one-hundredth of a degree, which for concentrated solutions where the elevation is from three to ten or more degrees would only be one in from three to ten hundred, and consequently negligible, the more so because at these concentrations it is not supposed the ionization coefficients are more than rough approximations. It should be remembered, however, that the ionization coefficients enter the calculations of values of the elevation constant in the form $1 + \overline{n - 1}\alpha$.

In the following tables "ionization coefficient" stands for μ_v/μ_∞, where μ_v is the equivalent conductivity at a dilution represented by v, where the latter is the number of litres to the gramme equivalent, and μ_∞ the equivalent conductivity at infinite dilution.

Ammonium Sulphate.

Grms. Salt added to 25 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
2·351	·944	·141	·081	·576	525
1·3148	5·04	·860	·398	·416	526
8·1906	24·8	4·34	2·132	·242	591
11·3674	31·4	5·52	3·014	·202	606
15·7030	38·8	6·50	4·298	·196	651
16·4862	39·9	6·94	4·576	·194	666
17·2096	41·0	7·10	4·979	·192	682
18·0360	42·1	7·22	5·317	·188	700
18·9242	43·3	7·32	5·374	·186	678
20·2898	44·1	7·46	5·608	·184	647
22·1284	47·2	7·84	5·822	·182	644
23·9964	49·2	8·34	6·258	·176	629

Ammonium Iodide.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·5798	3·72	·260	·290	·774	524
1·7398	10·58	·775	·790	·678	523
2·7860	15·9	1·226	1·250	·624	588
3·8908	20·10	1·624	1·760	·578	610
4·9696	25·2	2·055	2·335	·534	642
6·0348	29·1	2·446	2·846	·488	674
7·0862	32·5	2·805	3·392	·444	706
8·0540	35·4	3·140	3·870	·416	722
9·1206	38·2	3·458	4·374	·390	733
10·2102	40·9	3·779	4·950	·356	761
10·7614	42·3	3·976	5·361	·352	784
15·3904	51·1	4·714	7·664	·322	796
17·5818	54·4	5·150	8·700	·292	809
19·1904	56·6	5·83	9·568	·262	840
20·1800	57·8	5·97	10·154	·256	852

Cadmium Iodide.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·6600	4·296	·232	·077	·217	514
1·1440	7·22	·413	·131	·176	523
1·8258	11·05	·655	·191	·145	520
2·3248	13·65	·855	·243	·130	521
2·8564	16·27	1·055	·308	·119	519
3·7138	20·17	1·350	·381	·112	500
4·4524	23·24	1·580	·461	·107	503
5·1780	26·05	1·838	·556	·101	524
5·9198	28·72	2·125	·633	·094	526
6·6506	31·15	2·388	·725	·089	538
7·3876	33·45	2·625	·824	·083	554
8·1910	35·78	2·859	·925	·078	562
8·9688	37·90	3·101	1·022	·073	571
9·7522	42·15	3·678	1 099	·059	575

Lithium Bromide.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·3122	2·079	·262	·274	·718	518
·6352	4·142	·584	·532	·654	562
·9750	6·228	·764	·791	·608	595
1·3230	8·258	1·051	1·085	·564	630
1·6108	9·89	1·260	1·428	·548	665
2·0858	12·43	1·549	1·798	·526	698
2·4926	13·33	1·731	2·199	·492	736
2·9192	16·57	2·243	2·695	·476	782
3·3126	18·39	2·732	3·171	·448	859
3·7698	20·42	2·945	3·741	·434	874
4·2190	22·31	3·286	4·359	·416	920
5·1774	26·05	3·94	5·765	·376	1026
6·1592	29·54	4·48	7·421	·344	1136

Ammonium Bromide.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·4134	2·735	·368	·275	·754	509
·8424	5·427	·749	·542	·688	529
1·2970	8·11	1·09	·814	·646	537
1·7148	10·45	1·42	1·076	·626	545
2·1324	12·67	1·74	1·345	·606	557
2·5278	14·67	2·14	1·596	·586	567
2·9588	16·76	2·29	1·871	·564	577
3·8112	20·59	2·83	2·436	·533	587
4·6976	24·22	3·34	2·968	·518	595
5·5134	27·28	3·77	3·511	·482	610
6·8608	31·8	4·41	4·431	·452	623
7·8588	34·8	4·83	5·003	·434	638
9·7250	39·8	5·53	6·224	·414	645
10·5654	41·8	5·81	6·654	·376	656

Ammonium Chloride.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
1·5620	9·60	1·852	1·662	·598	527
2·0254	12·11	2·345	2·171	·562	540
2·5412	14·70	2·879	2·750	·534	557
3·0066	16·98	3·338	3·344	·510	562
3·6610	19·94	3·922	4·160	·478	606
4·1452	22·03	4·365	4·880	·456	636
4·9976	25·37	5·042	5·813	·428	643
5·5688	27·48	5·412	6·598	·412	661
6·3358	30·12	6·022	7·564	·388	678
7·0132	32·30	6·420	8·449	·372	705

AMMONIUM IODIDE.

Grms. Salt added to 25 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·3472	1·38	·105	·082	·854	506
1·1884	4·58	·354	·272	·764	510
3·2344	11·56	·897	·805	·664	542
4·6552	15·8	1·233	1·198	·624	572
6·0546	19·6	1·533	1·608	·592	602

POTASSIUM IODIDE.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
1·0312	6·55	·515	·394	·732	500
2·2370	13·15	·879	·866	·672	543
3·5122	19·28	1·368	1·350	·650	573
4·4084	23·08	1·695	1·721	·610	600
5·3076	26·53	1·978	2·146	·594	630
6·4266	30·44	2·050	2·677	·555	663
7·3928	33·4	2·665	3·184	·541	691
8·5136	36·87	2·965	3·758	·525	712
9·6638	39·67	3·341	4·360	·508	740
10·6884	42·11	3·660	4·901	·490	765
12·4771	45·9	4·16	5·955	·462	782
14·4472	49·5	4·62	6·709	·436	800

LITHIUM CHLORIDE.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·1514	1·01	·250	·231	·695	516
·5718	3·74	·922	·743	·568	522
1·0162	6·46	1·28	1·592	·534	633
1·5220	9·38	2·23	2·547	·462	710
1·9398	11·66	2·87	3·438	·426	775
2·4426	14·25	3·60	4·649	·384	856
2·9072	16·51	4·25	6·017	·344	959
3·4228	18·88	4·70	7·542	·322	1009
3·9494	21·18	5·31	9·294	·294	1133
4·5394	23·60	5·98	11·419	·264	1243

SODIUM CHLORIDE.

Grms. Salt added to 25 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·1514	·64	·141	·097	·854	501
·3266	·92	·203	·198	·804	496
2·0520	7·20	1·38	1·332	·612	578
2·2738	7·94	1·52	1·482	·602	581
2·3448	8·20	1·58	1·619	·596	595
2·7724	9·66	1·84	1·842	·572	610
2·8724	10·35	1·96	1·971	·562	624
3·1325	10·88	2·08	2·132	·552	632
3·3805	11·76	2·26	2·313	·538	637
3·6801	12·78	2·44	2·551	·522	656
3·8391	13·30	2·52	2·689	·516	666
3·9887	13·81	2·62	2·818	·508	672
4·1247	14·40	2·70	2·936	·502	684

LITHIUM NITRATE.

Grms. Salt added to 15 c.c. Solvent.	Per cent. Composition.	Grm. eqs. per Litre.	Elevation of Boiling Point	Ionization Co-eff.	Elevation Constant.
·3698	2·45	·312	·264	·582	512
1·1922	7·50	1·215	·841	·454	522
2·0796	12 34	2·025	1·516	·406	530
2·9666	16·85	2·788	2·241	·386	553
3·7660	20·40	3·371	2·918	·338	588
4·9920	24·84	4·118	3·921	·316	605
5·5344	27·36	4·62	4·428	·280	659
7·0466	32·41	5·39	6·160	·262	702
8·2510	35·95	5·98	7·200	·256	715
9·5464	39·34	6·52	8·496	·252	720

The values given in the above tables for the elevation constant show that, for the salts for which results are given, high values again make their appearance for the concentrated solutions.

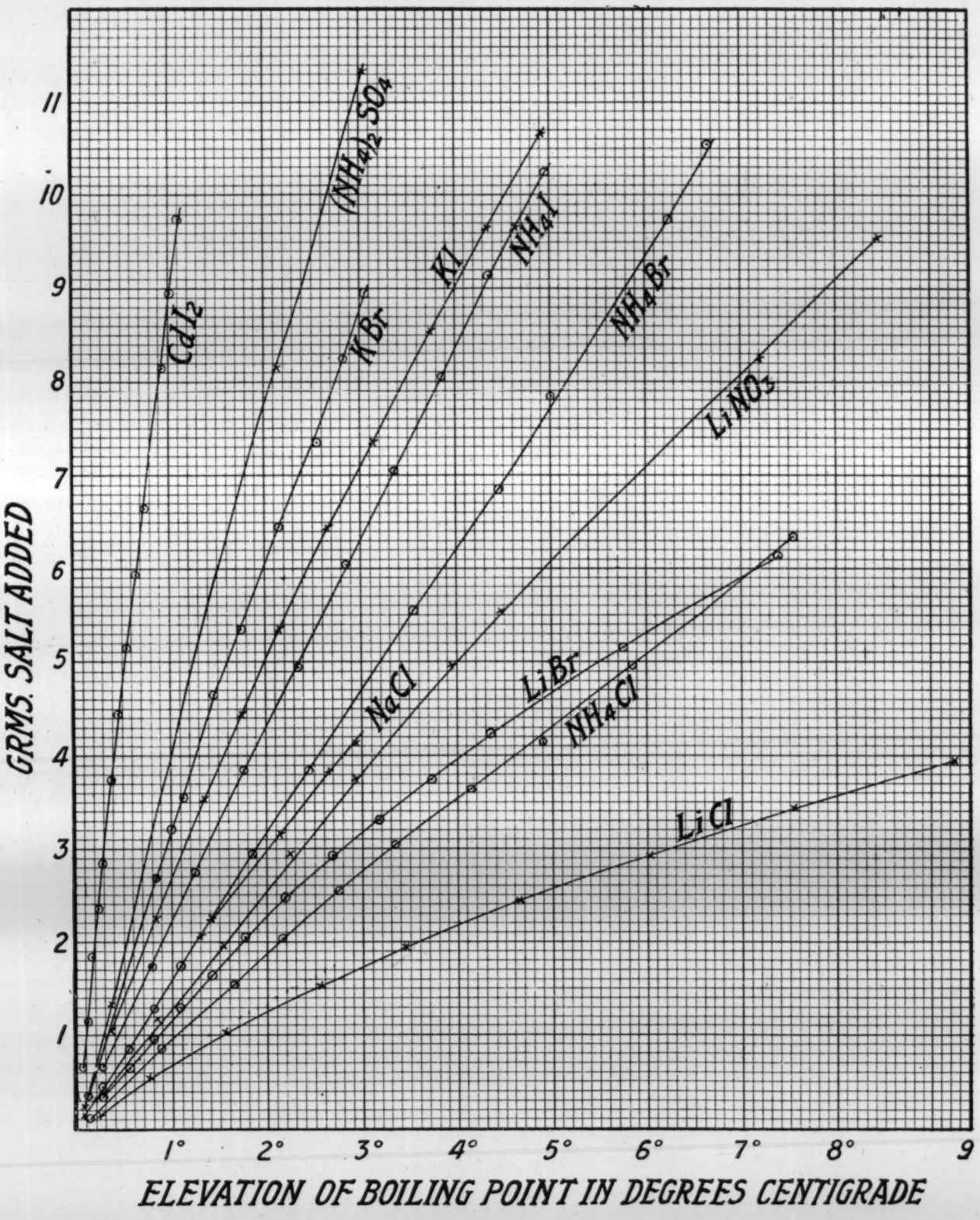
GRMS. SALT ADDED
1
2
3
4
5
6
7
8
9
10
11
CdI2
(NH4)2 SO4
KBr
KI
NH4I
NH4Br
LiNO3
NaCl
LiBr
NH4Cl
LiCl
1°
2°
3°
4°
5°
6°
7°
8°
9
ELEVATION OF BOILING POINT IN DEGREES CENTIGRADE

FIG. 12.

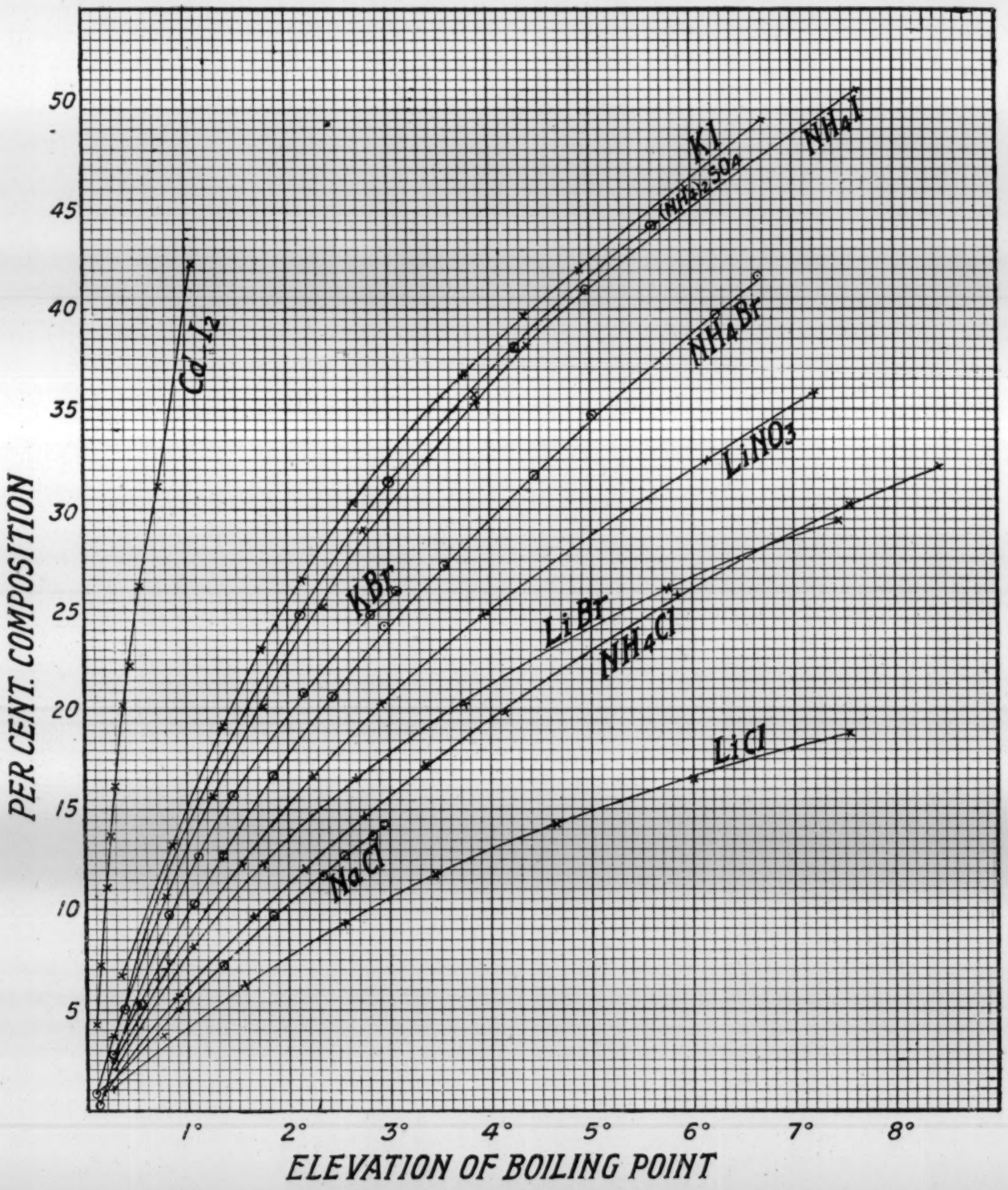
PER CENT. COMPOSITION
50
45
40
35
30
25
20
15
10
5
1°
2°
3°
4°
5°
6°
7°
8°
ELEVATION OF BOILING POINT
CdJ2
KI
(NH4)2SO4
NH4I
NH4Br
LiNO3
KBr
LiBr
NH4Cl
NaCl
LiCl

FIG. 13.

Before passing on to discuss these high values, it is desirable to look at plotted curves and consider what information may be obtained from them. For this purpose curves have been drawn for which I have plotted elevation of the boiling point in degrees Centigrade successively against (1) grammes of salt added to a constant amount of water, (2) percentage composition, (3) gramme equivalents per litre.

From the tables which have been given for concentrated solutions, and the curves for which gramme equivalents have been plotted against elevation of the boiling point in degrees Centigrade given below, it will be seen that the concentration has in several instances been as great as six or seven gramme equivalents per litre.

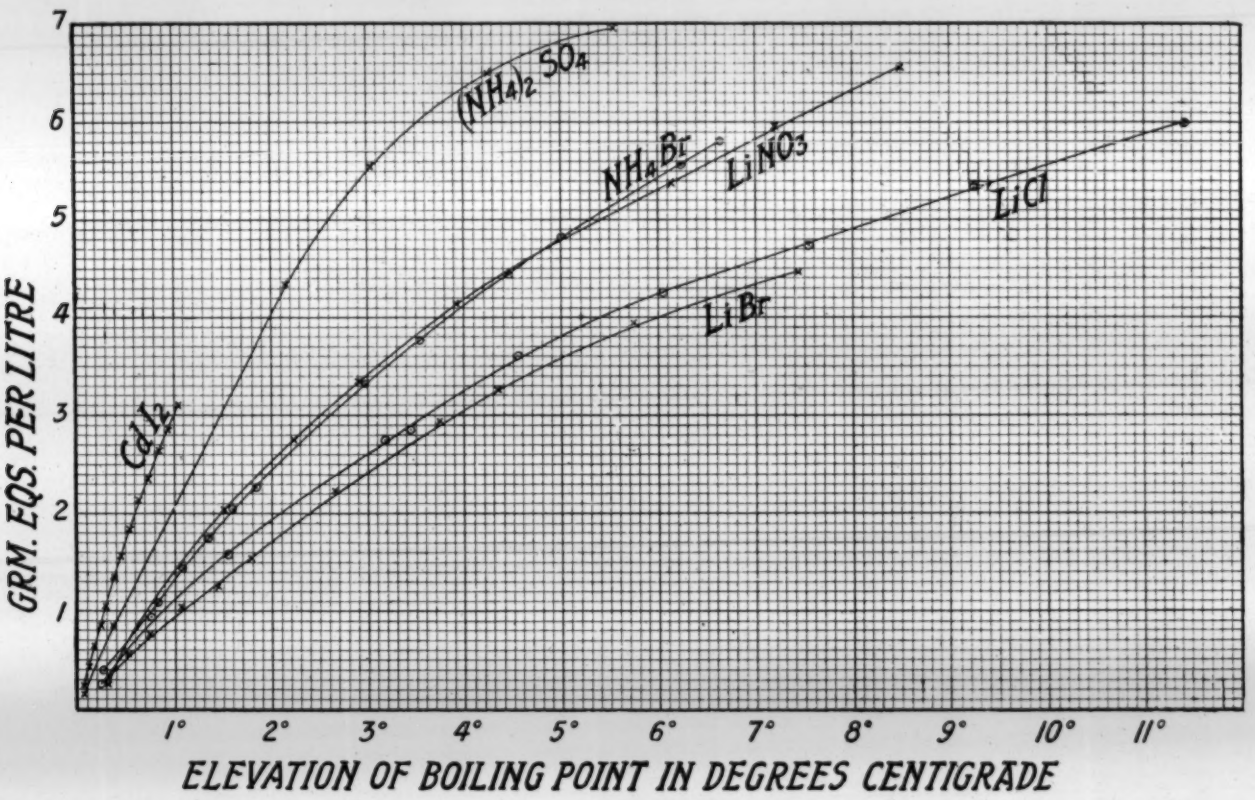

FIG. 14.

Considering that so high concentrations have been reached, the straightness of a considerable number of the curves (see page 222) for which grammes of salt added have been plotted against elevation of the boiling point in degrees, is noteworthy. This is particularly so for the curves for cadmium iodide, ammonium sulphate, ammonium iodide, ammonium bromide, and lithium nitrate. The same is true in a smaller degree for the curves for sodium chloride, sodium bromide, and ammonium chloride, and in a still less degree for the curve for lithium chloride.

The curves given above on pages 222, 223, and 224 illustrate how change in plotting affects curvature, those on page 222 being much straighter than either those on page 223 or page 224. The curves on page 224 indicate that, for concentrated solutions generally, the boiling-point elevation increases more quickly than the number of gramme equivalents per litre, and those on page 223 indicate that the elevation of

the boiling point also increases more quickly than percentage composition, each set of curves being concave towards the elevation axis, whereas the straightness of those on page 222 show that the amount of salt, added to a constant amount of water and elevation of the boiling point, increase as a rule fairly proportionately even to high concentrations.

When curves are drawn with elevation per gramme equivalent as ordinates and gramme equivalents per litre as abscissæ, these curves exhibit a * minimum point. Those given on page 226 have been drawn from the following data (fig. 15).

Ammonium Iodide.			Ammonium Bromide.			Cadmium Iodide.		
Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.
·260	·290	1·11	·368	·275	·74	·232	·077	·33
·775	·790	1·01	·749	·542	·72	·413	·131	·317
1·220	1·250	1·02	1·09	·814	·74	·655	·191	·291
1·624	1·760	1·08	1·42	1·076	·75	·855	·243	·285
2·055	2·335	1·13	1·74	1·345	·77	1·155	·308	·266
2·446	2·846	1·16	2·04	1·596	·78	1·350	·381	·282
2·805	3·392	1·20	2·29	1·871	·81	1·580	·461	·290
3·140	3·870	1·23	3·34	2·968	·88	1·838	·556	·302
3·458	4·374	1·26	3·77	3·511	·93	2·388	·725	·303
3·779	4·950	1·30	4·41	4·431	1·00	2·625	·824	·313
4·714	7·664	1·62	4·83	5·003	1·03	2·859	·925	·322
5·83	9·568	1·64	5·53	6·224	1·12	3·101	1·022	·329
5·97	10·154	1·76	5·81	6·654	1·14			

Lithium Bromide.			Lithium Chloride.			Lithium Nitrate.		
Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.	Grm. eqs. per Litre.	Elevation of Boiling Point.	Elev. per Grm. eq.
·262	·274	1·04	·250	·231	·92	·312	·264	·84
·584	·532	·91	·922	·743	·80	1·215	·841	·70
1·051	1·085	1·03	·158	1·592	1·04	2·025	1·516	·75
1·260	1·428	1·13	2·23	2·547	1·14	2·788	2·241	·81
1·549	1·798	1·16	2·87	3·438	1·19	3·371	2·918	·86
2·243	2·695	1·20	3·60	4·649	1·29	4·118	3·921	·95
2·945	3·741	1·27	4·25	6·017	1·41	4·62	4·428	·96
3·286	4·359	1·33	4·70	7·542	1·60	5·39	6·160	1·14
3·94	5·765	1·46	5·31	9·294	1·75	5·98	7·200	1·20
4·48	7·421	1·65	5·98	11·419	1·90	6·52	8·496	1·28

Curves are given (fig. 16) for which μ_v/μ_∞ where μ_v represents equivalent conductivity at dilution v and μ_∞ represents that at infinite dilution, has been plotted against the value obtained at v for the boiling-point elevation constant. These

* See page 226.

curves are all made up of two portions, the one a rectilinear portion running from higher to lower values of μ_v/μ_∞ (and consequently from higher to lower dilution) parallel to the μ_v/μ_∞ axis, and approximately along the 520 elevation constant line; the other a portion, either approximately rectilinear or but slightly curved, and running away from the μ_v/μ_∞ axis and towards the elevating constant axis. The various curves thus appear on the diagram as having coincident portions forming a common trunk and non-coincident portions forming branches.

It is not supposed that in every instance the curves change direction so sharply as indicated by those drawn.

From Professor* MacGregor's discussion of freezing-point data, it may readily be

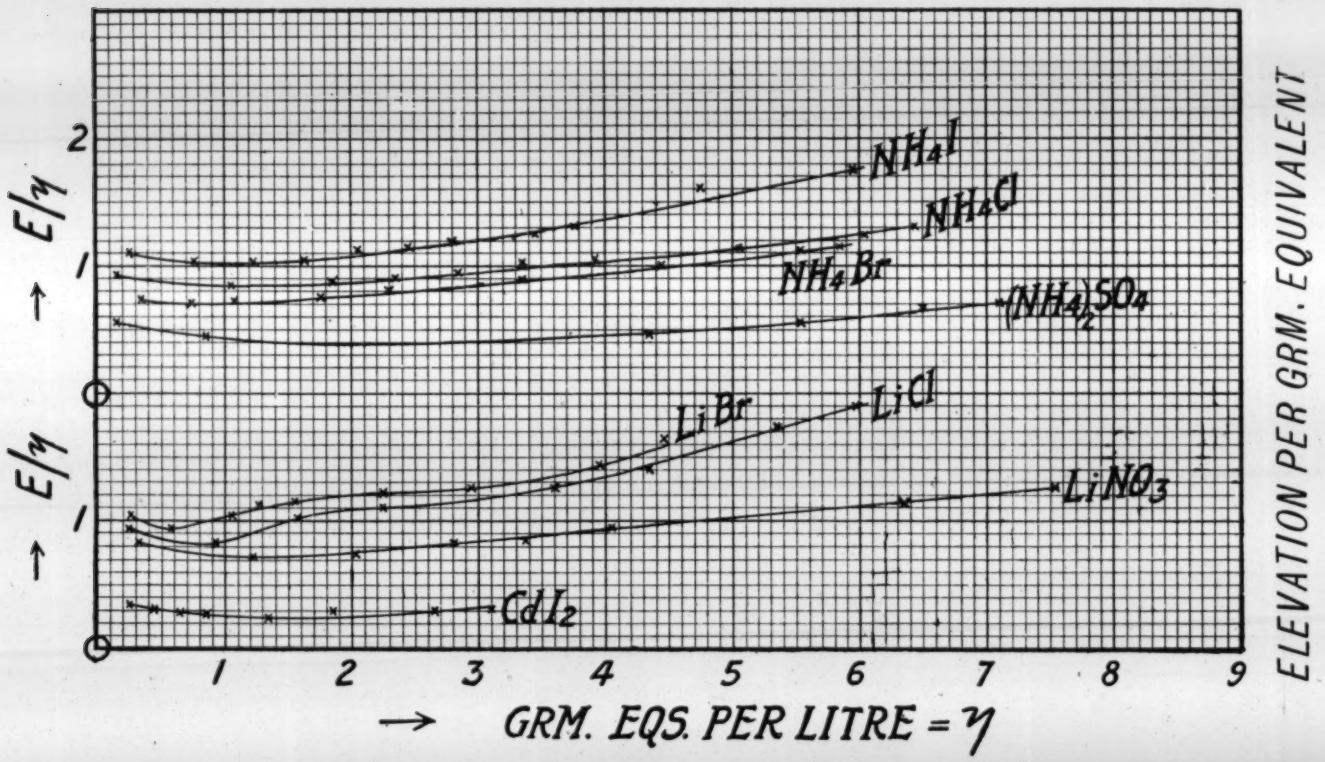

Fig. 15.

shown that a similar diagram with freezing-point depressions as abscissæ would give curves of the same kind, but that the curves would frequently be found to branch off from the common trunk at points corresponding to higher dilution than in the boiling-point diagram. This would seem to indicate what Biltz† has found, that from the elevation of the boiling-point point of view salts act more normally than from the depression of the freezing-point point of view.

Passing on from these observations, we will now consider the meaning of the high values which have been obtained for the elevation constant for concentrated solutions.

Can they be explained on the hypothesis that the ions and the molecules have

* *Phil. Mag.*, 1900, p. 505.

† *Zeit. phys. Chemie*, 40, 204 (1902).

values for the elevation constant which differ very considerably, the value for the ions being comparatively small?

So much might be suggested by the fact that for dilute solutions the elevation constant approaches one value, for concentrated solutions it increases with the con-

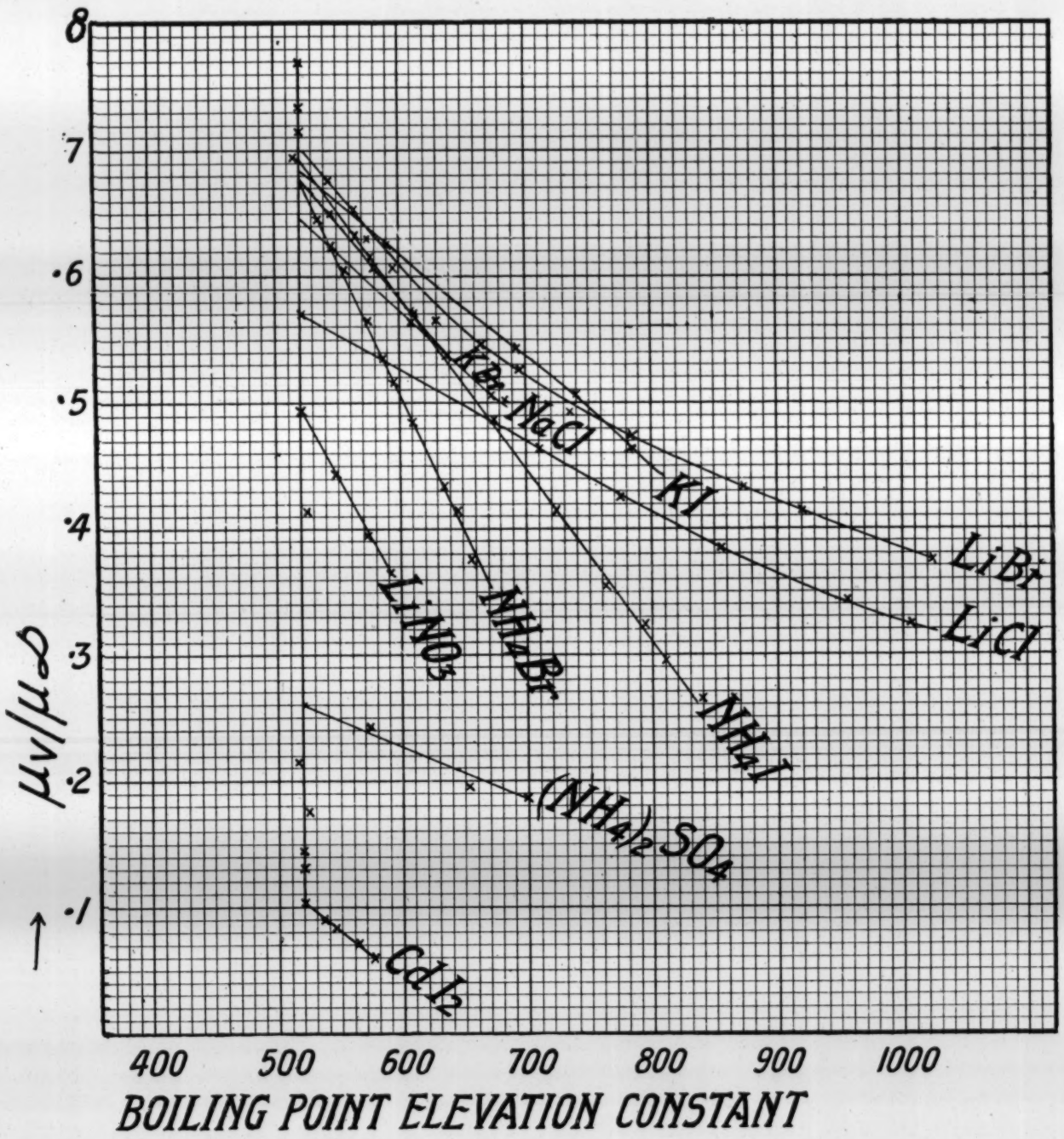

FIG. 16.

centration. In the one case there are few molecules present, in the other comparatively few ions. This hypothesis would be supported by the fact that, for several salts at the same ionization and at a not very different concentration, nearly equal values of the elevation constant were obtained.

To test this assumption, I turned to non-electrolytes to see what values of the elevation constant these would give. For such salts molecular, as distinct from ionic, values of the constant are obtained, there being little or no ionization. Except* in one or two instances, the values obtained were not anything like so large as the above assumption would require.

Mannite.		
Grms. Salt added to 50 c.cs. Water.	Elevation of Boiling Point.	Elevation Constant.
·4808	·143	530
·9552	·171	536
1·4346	·191	536
1·8936	·226	535
2·3536	·254	530
2·7486	·278	537
3·2046	·305	536
3·8536	·344	537
4·2782	·367	537
4·7340	·396	538
5·3976	·429	537
5·8546	·459	537
6·3432	·490	538
6·8672	·520	535

Tartaric Acid.		
Grms. Salt added to 15 c.cs. Water.	Elevation of Boiling Point.	Elevation Constant.
·2566	·033	489
1·1542	·168	541
2·3444	·344	545
3·2162	·484	559
4·5206	·687	563
6·8758	1·079	582
8·4976	1·349	588

Cane Sugar.		
Grms Salt added to 50 c.cs. Water.	Elevation of Boiling Point.	Elevation Constant.
·2500	·045	855
·7238	·095	938
1·1906	·189	969
1·8944	·229	978
2·5644	·289	998

Boracic Acid.		
Grms. Salt added to 50 c.cs. Water.	Elevation of Boiling Point.	Elevation Constant.
·7516	·131	520
2·2096	·512	532
4·4920	·911	561
7·5972	1·485	562

We shall now consider the results obtained from electrolytes which dissociate but little.

Cadmium idiode and cadmium chloride are electrolytes which dissociate slightly at ordinary concentrations. Consequently we should expect, on the above explanation, that high values of the elevation constant would be obtained, there being many molecules and few ions in a solution. On the contrary, ordinary values of the constant were obtained, as will be seen from the following tables :—

* See Cane Sugar.

Cadmium Iodide.

Grm. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·445	·169	·167	520
·639	·218	·146	516
1·048	·286	·119	519
1·210	·354	·115	521
1·308	·436	·113	519
1·563	·517	·107	522
1·825	·577	·101	510
2·021	·682	·096	526

Cadmium Chloride.

Grms. eqs. per Litre.	Elevation of Boiling Point.	Ionization Co-eff.	Elevation Constant.
·330	·129	·251	517
1·512	·484	·132	520
2·446	·754	·102	516
3·182	1·022	·084	523
3·884	1·154	·066	517
4·390	1·324	·061	525
4·936	1·504	·056	518
5·892	1·864	·048	517
6·550	2·110	·042	529

These several results in combination show that largely different values of the constant for the ion and the molecule are not the cause of the increase of the elevation constant with concentration. Having shown that the high values obtained for the elevation constant are not accounted for by the supposition put forward, we will now consider the hydration theory.

When curves are drawn (see page 226) for which elevation of the boiling point per gramme equivalent is plotted against the number of gramme equivalents per litre, these curves exhibit a minimum, and consequently show that, notwithstanding the decrease of ionization, elevation of the boiling point per gramme equivalent increases with concentration after a certain concentration has been reached, the portion of all the curves for concentrated solutions bending towards the equivalent elevation axis.

On the hydration theory this curvature is at once explained as due to the quantity of active water being diminished through water molecules combining with salt particles (molecules or ions). Consequently the elevation increases as concentration increases, so long as the active water continues to diminish.

The minimum point is explained by the falling off of hydration until its effect is balanced by change in ionization and the curvature of the portion of the curve between the minimum point and the equivalent elevation axis, as due to increase of ionization.

As the change in ionization is not very considerable for a small range of concentration, the fact that between the minimum point and the equivalent elevation axis it has an influence which has a very considerable effect on the curve, indicates that for this portion of the curve hydration must have an inappreciable influence, or, in other words, that for dilute solutions the hydration, if any, is negligible, as has been previously pointed out by various observers.

For the curves* (fig. 16) for which values of μ_v/μ_∞ have been plotted as ordinates and values of the elevation constant as abscissæ, it has been noted that the curves consist of approximately rectilinear portions branching from a common rectilinear trunk at points corresponding to different concentrations in the case of different salts. The branching off of these curves is readily explained on the hydration theory as due to

* Page 227.

diminution of the amount of active water and consequent increase of the elevation constant when hydration is not taken into account in its computation.

The ionization at which the curves change direction gives a means of determining at what ionization hydration commences and the corresponding concentrations may be obtained.

The following rough approximations for the commencement of hydration have been obtained in this way.

CdI_2	commences	to	hydrate	at	1·8 gramme eqs. per litre.
$LiNO_3$	,,	,,	1·0	,,	,,
NH_4Cl	,,	,,	1·0	,,	,,
NH_4Br	,,	,,	·74	,,	,,
NH_4I	,,	,,	·70	,,	,,
LiBr	,,	,,	·26	,,	,,

It has been pointed out that the value of the elevation of the boiling-point constant does not change its apparent value by the ordinary method of computation until a certain ionization is reached. Further, when the equivalent depression of freezing point is plotted against equivalent concentration, the curves exhibit a minimum; and in the curves when equivalent elevation is plotted against equivalent concentration, as given by BILTZ,* JONES and GETMAN,† and those obtained by myself,‡ a minimum also is found. Each indicates that there is no hydration in dilute solutions.

On this point JONES and GETMAN § say: "In the dilute solutions there is no evidence of the existence of hydrates."

Passing on to consider hydration more minutely, the question arises—Do the *ions*, or *molecules*, or *both*, hydrate?

The answer which JONES and GETMAN || give to this question is: "It is difficult to say whether it is the molecules, or the ions, or both, that form the hydrates in concentrated solutions, since all such solutions that we have studied contain both molecules and ions. Since, however, these solutions that are most concentrated and therefore the least dissociated show the greatest amount of hydration, it seems probable that it is the molecules and not the ions that combine with water and form hydrates." This conclusion ¶ has been modified.

JONES and GETMAN found the above idea on the fact that the more concentrated solutions are those in which hydration is greatest. Where there are relatively few molecules, there is no hydration.

If one were only to consider a single salt or a few salts of the same kind, preferably those which ionize highly, then one might see ground for their conclusion; but when salts which ionize very differently are considered, it is seen that, as a rule, those which ionize highly commence to hydrate at the smaller concentration, and it is these which have the smaller number of molecules at this concentration, and many

* *Zeit. phys. Chemie*, 40, 204 (1902). † *Am. Chem. Jour.*, 31, 325 (1904). ‡ Page 226.
§ *Am. Chem. Jour.*, 31, 355 (1904). || *Am. Chem. Jour.*, 31, 356 (1904). ¶ *Am. Chem. Jour.*, 33, 583 (1905).

times less molecules in solution than some of those which ionize less, when these commence to hydrate.

One sees, therefore, that in case many ions are immediately formed, hydration commences in dilute solutions, and that where the salt ionizes feebly a greater concentration is reached, sometimes a very much greater (pages 220, 221, and 230).

This indicates that the commencement of hydration is dependent on the number of ions in solution, not on the number of molecules, and indicates that the ions hydrate.

With regard to the non-electrolytes, ROTH * finds that for various non-electrolytes considered there is a divergence of about 2 per cent. from the depression constant; the meaning of which is that, so far as his observations went, there was no hydration.

P. W. ROBERTSON, with † regard to the esters in phenol solution, finds "that they have either a high initial depression and a negative rate of association, or associate slightly in dilute solutions and thus exhibit a minimum." Although these results were obtained from phenol as solvent, nevertheless they are interesting from the standpoint of hydration.

LOOMIS ‡ found for non-electrolytes "that depression of the freezing point is either the same at all concentrations or changes gradually when referred to one thousand grammes of the solvent."

These results indicate that some non-electrolytes hydrate, others do not.

The results I have obtained for non-electrolytes are in harmony with those of LOOMIS, ROTH, and ROBERTSON.

In this respect possibly the electrolytes resemble the non-electrolytes, in some instances their molecules hydrate, in others not.

HYDRATION DATA.

We have now reached a point when it is desirable to obtain hydration data. Consequently I have made out the following formulæ for (1) both molecular and ionic hydration, (2) ionic hydration only, and (3) molecular hydration only, so that calculations may be made of the number of molecules of water combined with one molecule or ion of salt, or with each according as hydration may be looked upon as only molecular, ionic alone, or both molecular and ionic.

To obtain these results it was essential to know the number of grammes of combined water, *i.e.* the amount of solvent taken up by the salt particles, or combined with these.

I. To obtain the number of grammes of combined or associated solvent.

If C be the value of the so-called boiling-point constant obtained at a certain concentration, we have

$$C = \frac{m\mathrm{W}(\Delta \mathrm{E})}{(1 + \overline{n-1}a)\Delta w}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

* *Zeit. phys. Chemie*, 43, 539–564 (1903).

† *Jour. Chem. Soc.*, Oct. 1905.

‡ *Rev. Phys.* 12, 220 (1901).

The hydration theory gives

$$C' = \frac{mW'(\Delta E)}{(1 + \overline{n-1}\alpha)\Delta w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where C′ is the theoretical value of the constant and W′ is the amount of active water in the solution at the concentration, that is, the amount of water not in a state of combination with salt. We have, therefore, dividing (2) by (1)

$$\frac{C'}{C} = \frac{W'}{W}$$

$$W - W' = \frac{W(C - C')}{C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Having shown how to calculate the amount of combined water, we shall consider the method of its distribution under the several possible forms of hydration.

The amount of water which is regarded as combined may be associated either with (1) both molecules and ions, (2) with ions only, (3) with molecules only.

II. (*a*) To obtain the number of molecules of combined water per molecule or ion on the assumption that both molecules and ions hydrate.

If W and w be weight of water and of salt added to the water respectively, W′ the active or uncombined water, α the ionization coefficient at the concentration, then $\frac{W - W'}{18}$ is the number of gramme molecules of water present, and $\frac{w(1 + \overline{n-1}\alpha)}{m}$ is the number of gramme particles (molecules or ions) of salt in solution.

The ratio gives the number of molecules of water per molecule or ion of salt in solution. The number of molecules of water per molecule or ion of salt dissociated or undissociated, therefore, is equal to

$$\frac{(W - W')m}{18w(1 + (n-1)\alpha)}.$$

(*b*) The hydration per ion on the assumption that ions only hydrate is

$$\frac{(W - W')m}{18.n.\alpha.w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

(*c*) If the hydration is only molecular, the hydration per molecule is given by the formula

$$\frac{(W - W')m}{18(1 - \alpha)w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

The tables which follow contain the results of computations for ammonium and lithium salts. (When making the observations, 25 and 15 cubic centimetre tubes were used.)

[TABLES.

AMMONIUM CHLORIDE.

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
1·852	·3	·36	·5	1·4
2·345	·7	·60	·92	2·3
2·879	1·0	·80	1·1	2·6
3·338	1·6	1·0	1·5	3·2
3·922	2·1	1·2	1·7	3·3
4·365	2·6	1·1	1·9	3·1
5·042	2·9	1·1	2·0	3·0
5·412	3·2	1·2	2·0	2·9
6·022	3·4	1·0	1·5	1·9
6·420	3·9	1·1	1·3	1·6

AMMONIUM BROMIDE.—*First Series.*

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
·749	·3	1·2	1·4	8·0
1·09	·5	1·2	1·5	6·7
1·42	·7	1·3	1·8	6·5
1·74	1·0	1·6	2·1	6·4
2·14	1·2	1·6	2·1	6·5
2·29	1·5	1·7	2·3	6·3
2·83	1·7	1·6	2·2	5·4
3·34	1·9	1·4	2·4	4·5
3·77	2·2	1·3	2·3	4·1
4·41	2·5	1·3	2·2	3·6
4·83	2·8	1·3	2·2	3·4
5·53	2·9	1·1	2·0	2·7
5·81	3·1	1·1	2·1	2·5

AMMONIUM BROMIDE.—*Second Series.*

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molocules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
3·76	4·5	1·3	2	4·4
4·27	5·3	1·4	2·1	4·4
5·30	6·7	1·2	1·9	3·4
5·46	6·9	1·2	1·9	3·3
5·57	7·1	1·1	1·9	3·3

AMMONIUM IODIDE.

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
·897	1	1·5	2·5	8
1·233	2·3	2·8	3·2	10·6
1·533	3·6	3·0	4·4	11·7

AMMONIUM NITRATE.

Grm. eqs. per Litre.	Total Grms. hydrate Water.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
2·016	·4	·5	·7	1·4
2·842	·7	·6	1·0	1·8
3·324	·9	·6	1·0	1·7
3·846	1·0	·6	1·0	1·5
4·764	·6	·3	·5	·6
5·164	·3	·1	·2	·2

AMMONIUM IODIDE.

Grm. eqs. per Litre.	Total Grms. hydrate Water.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
1·226	1·7	3·0	2·9	13·4
1·624	2·2	2·9	3·9	11·0
2·055	2·9	3·0	4·4	10·7
2·446	3·4	3·0	4·7	8·9
2·805	3·9	3·0	5·0	7·7
3·140	4·6	3·2	5·3	7·9
3·458	4·5	2·7	5·0	6·2
3·779	4·7	2·7	5·2	5·5
3·976	5·0	2·6	5·3	5·7
4·714	5·1	2·2	4·1	4·5
5·150	5·4	2·0	4·2	4·1
5·83	5·6	1·9	4·5	3·1
5·97	5·2	1·9	4·0	2·7

AMMONIUM SULPHATE.

Grm. eqs. per Litre.	Total Grms. hydrate Water.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
·860	1·0	·022	2·2	1·7
4·34	3·5	1·2	2·3	1·8
5·52	4·4	1·0	2·3	1·7
6·50	5·9	1·0	2·0	1·6
6·94	6·3	1·0	2·5	1·7
7·10	6·7	1·0	2·4	1·5
7·22	7·2	·9	2·5	1·8
7·32	6·6	·9	2·3	1·5
7·46	5·7	·75	1·8	1·2
7·84	5·5	·71	1·6	1·1
8·34	4·7	·48	1·6	·68

The following hydration computations have been made for the salts of lithium:—

LITHIUM BROMIDE.

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
·584	1·1	5·0	6·2	30
·764	1·9	5·8	7·3	26
1·051	2·6	6·2	8·4	24
1·260	3·1	6·1	8·6	21
1·549	3·8	5·9	8·4	19
1·731	4·4	5·8	8·7	17
2·243	5·0	5·6	8·9	15
2·732	5·5	5·5	9·0	14
2·945	6·0	5·3	9·0	13
3·286	6·4	5·2	9·0	12
3·94	7·2	5·0	9·0	10
4·48	8·0	5·2	9·1	9·8

LITHIUM CHLORIDE.

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
1·28	2·7	3·1	6	13
2·23	4·0	4·2	6	11
2·87	4·9	4·0	7	10
3·60	5·8	4·0	7	9
4·25	6·8	4·1	7	8
4·70	7·2	4·0	7	7
5·31	8·0	3·6	8	6
5·98	8·6	3·5	8	6

[TABLE.

LITHIUM NITRATE.

Grm. eqs. per Litre.	Total water of Hydration in Grms.	Molecules of water of Hydration on the assumption that		
		Molecules and Ions hydrate. Per Mol. or Ion.	Ions only hydrate. Per Ion.	Molecules only hydrate. Per Mol.
2·025	·3	·38	·66	·88
2·788	·9	·84	1·5	1·9
3·371	1·7	1·2	2·8	2·6
4·118	2·1	1·2	2·4	2·3
4·62	3·1	1·5	3·9	3·0
5·39	3·9	1·6	4·0	2·8
5·98	4·1	1·5	3·6	2·5
6·52	4·1	1·3	3·3	2·2

The hydration data just given show that, if hydration be molecular alone, a maximum hydration per molecule is quickly attained and then gradually falls off for all the salts considered. In several instances the highest hydration per molecule is obtained for the most dilute solution used.

If the hydration be ionic alone, a maximum hydration per ion is gradually reached with increase of concentration, which for the ammonia salts continues steady for a considerable range of concentration and thereafter falls off gradually. In the case of the chloride and bromide of lithium the ionic hydration seems to increase with concentration up to the limit of concentration reached.

If the hydration be that of both molecules and ions, a maximum hydration per molecule or ion is gradually reached which remains constant for a certain range of concentration and then falls off, and seems to do so for all the salts for which hydration data are given.

It will be seen from the above tables that the number of molecules of combined water is greater for the lithium salts than for the corresponding ammonia salts under each hypothetical form of hydration. These high values might result in part from the hydration of the lithium ion being greater than that of the ammonia ion in case the hydration were only ionic, but the difference is so considerable for the chlorides and bromides as to suggest that perhaps the molecules of these salts also hydrate, which might also be suggested by these salts being deliquescent.

With this portion of the subject I hope to deal more fully in a later paper on Hydration.

On the question of ionic hydration the results of GARRARD and OPPERMANN * are interesting.

By an electrolytic process they find that the SO_4 ion takes up nine molecules of water of hydration, the bromine ion four, and the chlorine ion five molecules, and the

* *Göttinger Nachrichten*, p. 86 (1900, 1903).

NO_3 ion two and one half molecules of water of hydration, on the assumption that the hydrogen ion does not hydrate.

The above results are mean values of the several experiments made by GARRARD and OPPERMANN.

The values they obtained for the several ions considered are :—

Cl Ion.	Br Ion.	NO_3 Ion.	SO_4 Ion.
7·4	3·1	2·1	6·5
5·0	5·2	1·8	17·1
3·1	4·9	1·2	8·8
5·4	5·6	4·1	
1·6	2·9	2·7	
2·0	3·2	3·0	

Treating the results I have obtained for the ammonia salts as the above experimenters did theirs, that is, assuming that the NH_4 ion does not hydrate. As the ionic hydrations I have given above are mean values for the two ions, these must be doubled for monovalent and trebled if one be bivalent, under the above assumption, *i.e.* that the NH_4 ion does not hydrate.

The following are the results :—

Cl Ion.	Br Ion.	NO_3 Ion.	SO_4 Ion.
·10	2·8	1·2	6·6
1·84	3·0	2·0	6·9
2·2	3·6	2·0	6·9
3·0	4·2	2·0	6·0
		1·0	
3·4	4·2	·4	7·5
3·8	4·6		7·2
4·0	4·4		7·5
4·0	4·8		6·9
3·0	4·6		5·4
2·6	4·4		4·8
	4·4		4·8
	4·0		

The above figures show an agreement in hydration values which is scarcely less than striking when it is remembered they have been obtained by two wholly different methods.

Had GARRARD and OPPERMANN given the concentration or concentrations at which they worked, it would have been possible to make the comparison more complete.

For concentrations over a wide range, the hydration values I have obtained are nearly constant.

If GARRARD and OPPERMANN worked at a constant concentration, then my results would be in striking contrast to theirs, as for a considerable range of concentration I

have been able to strike off frequently approximately the same hydration value. It need only further be mentioned that GARRARD and OPPERMANN consider their error limit large.

The following two diagrams were drawn to show (1) the relation between the number of grammes of associated water and the elevation of the boiling point in degrees Centigrade, (2) the relation between grammes of associated water and the gramme equivalents per litre.

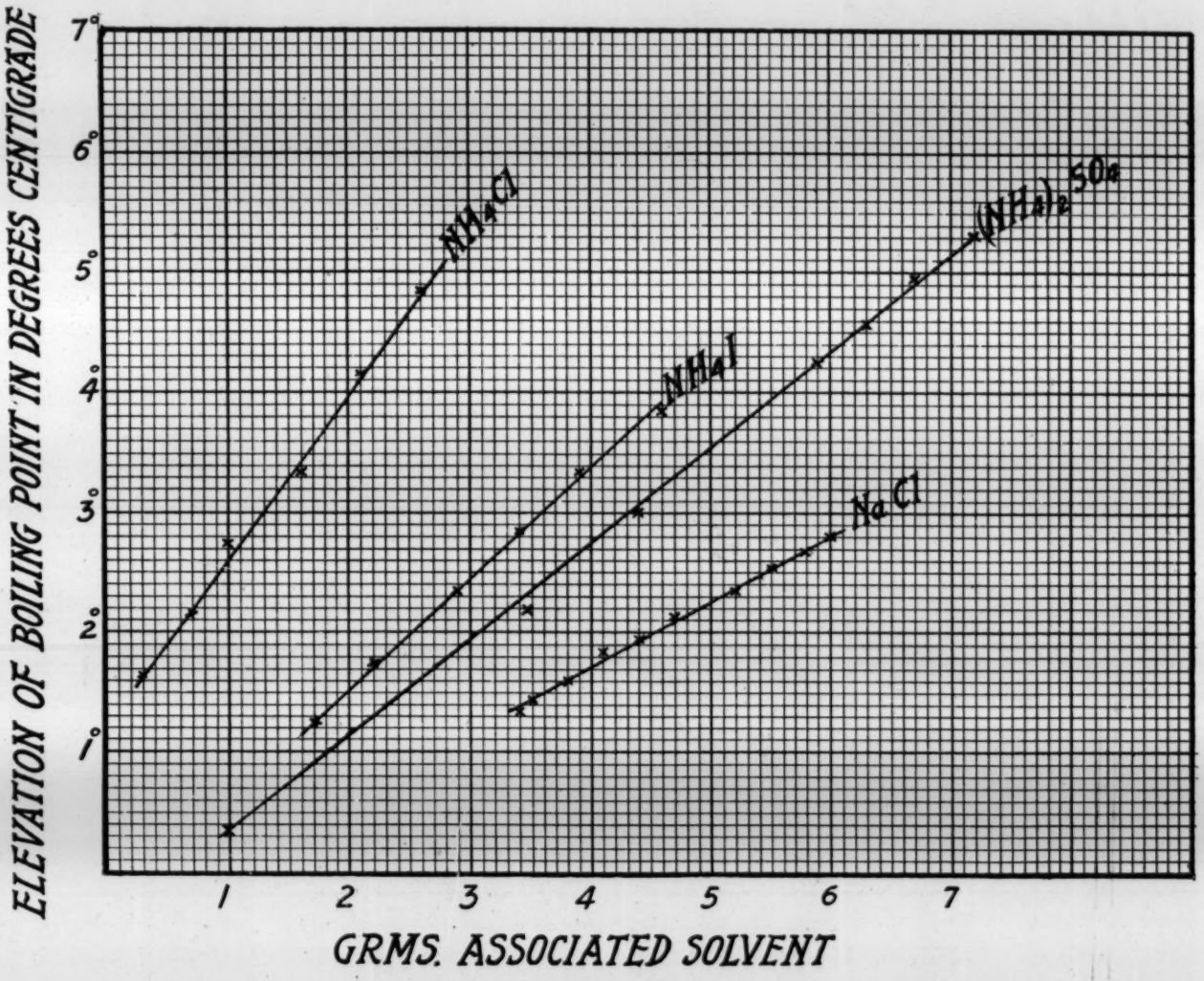

FIG. 17.

In the first instance approximately linear relations are seen to exist throughout ranges of boiling-point elevation of from 3 to 6 degrees Centigrade. In the latter case the curves are concave towards the gramme equivalent axis, the curves being approximately straight lines until a concentration of from three to four or five gramme equivalents is reached; which means that the rate of increase of hydration is fairly maintained up to these concentrations, but that a point is reached for the salts whose data have been plotted when the rate of increase of hydration with increase of concentration is not fully maintained.

Résumé of Results obtained.

(1) A method has been brought forward giving increased accuracy in boiling-point research, when water is used as solvent.

(2) A determination has been made of the so-called boiling-point constant for

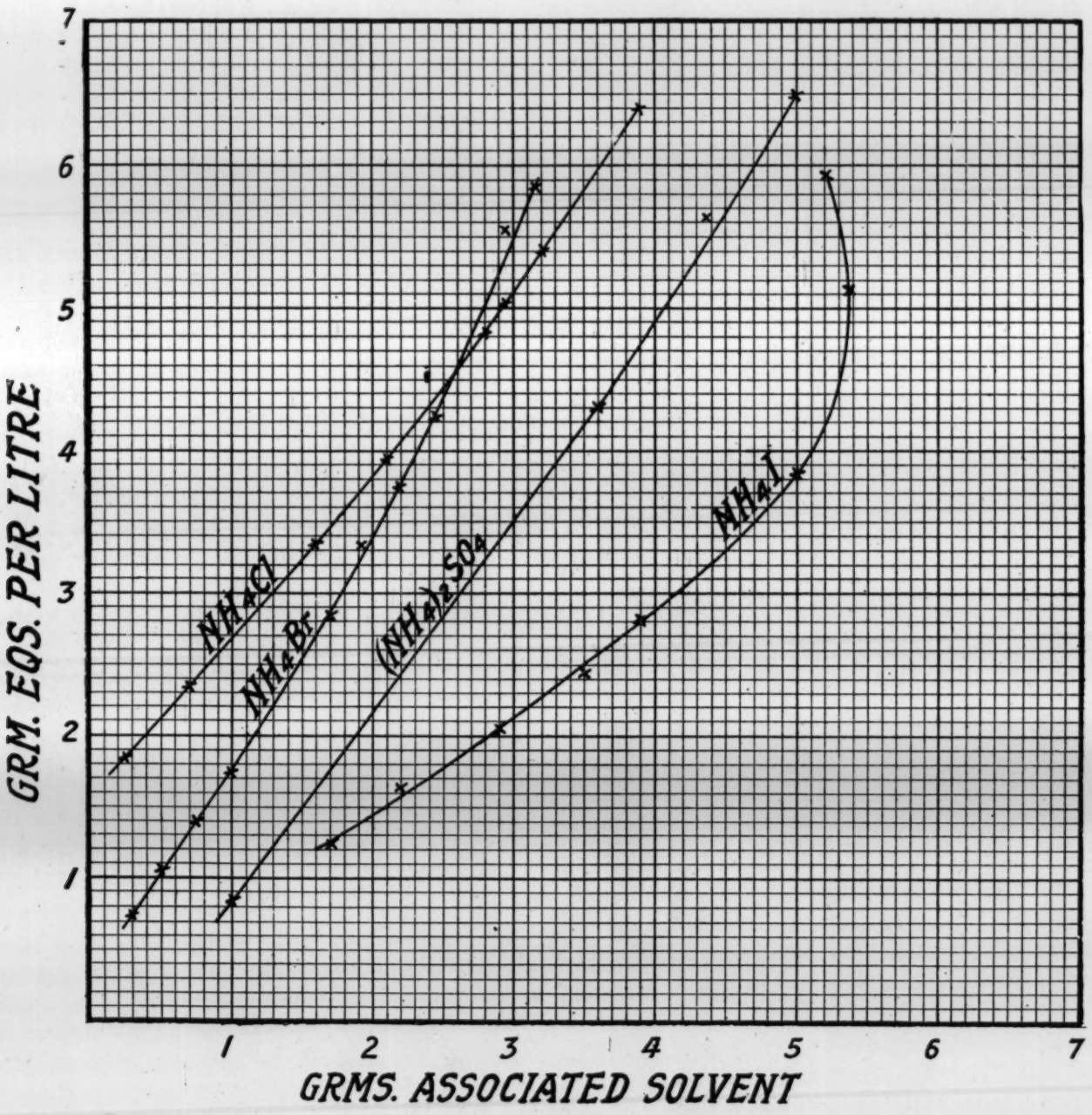

Fig. 18.

electrolytes. The results which are given indicate that for dilute solutions for all the salts considered the boiling-point elevation constant has a constant value represented approximately by the theoretical value 520, and that for some salts, notably those of caesium nitrate, cadmium iodide, and cadmium chloride, the value of the elevation constant, obtained experimentally, is approximately the theoretical value to concentrations

varying from two to six gramme equivalents per litre. But generally, when a certain concentration is reached, which varies for different salts, the value of the elevation constant increases with concentration when computed in the ordinary way.

(3) Molecular weight determinations have been successfully made for several salts, and are in striking contrast with those which have been made by other observers by the boiling-point method, these varying by as much as 20 per cent. as obtained by different observers. Those I have obtained only differ from the international atomic weight values by from one to one-tenth per cent.

(4) An improved method of obtaining conductivity values at the boiling point of the solvent has been given, and apparatus described.

(5) The results of observations on concentrated solutions, with a view to find out the meaning of the high values of the elevation constant for such solutions, are given, alternative theories being tested, and finally, these high values are ascribed to hydration.

(6) A minimum has been found in the curves obtained by plotting elevation per gramme equivalent against gramme equivalents per litre, which is in harmony with the results obtained both from the elevation of the boiling, and depression of the freezing, points of view, as given by other observers.

(7) Some salts commence to hydrate at a much greater dilution than others, as is shown by a comparison of the elevation constant obtained for the lithium and cadmium salts (pages 220 and 221). The indications are that those which ionize least commence to hydrate at the higher concentration.

(8) The hydration figures obtained indicate that, if association is molecular alone, its amount quickly reaches a maximum per molecule for the ammonia salts, and decreases gradually for higher concentrations.

If the hydration be ionic only, the maximum hydration per ion is reached gradually, which is steady until high concentrations are reached and then it decreases for the above salts.

If the hydration be that of both molecules and ions, a maximum hydration per molecule or ion is gradually reached which continues constant until considerable concentrations are reached.

(9) The molecular, the ionic, and the molecular ionic theories have been considered, and the conclusion arrived at that the ions hydrate, and probably the molecules also, in the case of deliquescent salts.

(10) The curves giving the relation between elevation of boiling point and grammes of combined or associated water show that between elevation of boiling point and association a linear relation exists for all the salts considered.

(11) The curves with values of μ_v/μ_∞ as ordinates and elevation of the boiling-point constant as abscissæ are made up of two portions. One approximately along the 520 elevation line, the other receding from this line, each portion being approximately a straight line.

By the aid of these curves the ionization at which hydration commences has been determined, and thence the concentration has been read off from concentration ionization curves for several salts.

(12) The computations which have been made of the number of molecules of water combined with one ion for the ammonia salts are in close agreement with those obtained by GARRARD and OPPERMANN, which has been shown by a comparison of data. For the salts of lithium the data I have obtained indicate a very much higher hydration for these salts, notably for the bromide and chloride.

Finally, I desire to return my best thanks to Professor MACGREGOR, under whose kindly and genial direction and interest this research was carried out, for his helpful discussion of difficult points and invaluable working hints.

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IX.—On the Relationship between Concentration and Electrolytic Conductivity in Concentrated Aqueous Solutions. By Professor John Gibson.

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Although great advances have been made during the last thirty years in our knowledge of dilute solutions, there has been no corresponding advance in respect of concentrated solutions. This is primarily due to the fact that hitherto no simple and general relationship has been discovered between the conductivity and the concentration of concentrated solutions of electrolytes. OSTWALD'S law of dilution holds only for dilute solutions of weak electrolytes, and the formulæ of RUDOLPHI and VAN T'HOFF are applicable only to dilute solutions of good electrolytes. It seems therefore important to inquire whether the difficulty may not be to some extent overcome by an alteration in the mode of representing the facts.

Our knowledge of the facts is mainly derived from the classical researches of KOHLRAUSCH. The following discussion is based throughout on the data given by KOHLRAUSCH and HOLBORN in Table I. of their invaluable compilation entitled *Leitvermögen der Electrolyte.*

The units adopted by KOHLRAUSH are :—

κ = Specific conductivity in ohm^{-1} c.m.$^{-1}$.
η = Concentration in gram equivalents per c.c.
m = 1000 η or gram equivalents per litre.
$\Lambda = \frac{\kappa}{\eta}$ = equivalent conductivity.
s = Specific gravity.

Formerly the concentration was expressed in percentages, but the advantage gained by expressing the concentration in terms of gram equivalents is obvious. This advantage is, however, not dependent upon the adoption of the unit of volume (c.c. or litre). On the contrary, by expressing the concentration of a concentrated solution in terms of the number of gram equivalents of the solute per unit *volume* of the solution, the relationship between the concentration and the mass of a concentrated solution is necessarily masked, because the solution of electrolytes in water is accompanied by changes in volume differing with each electrolyte and by no means negligible in concentrated solutions.

Let the following units be taken :—

κ = Specific conductivity in ohm^{-1} c.m.$^{-1}$.
γ = Concentration in gram equivalents per gram of solution.
Γ = 1000 γ.
$\Lambda_M = \frac{\kappa}{\gamma}$ (corresponding to $\Lambda = \frac{\kappa}{\eta}$).

For concentrated aqueous solutions of good electrolytes the relationship between Λ_M and Γ expressed in these units is, over wide ranges of concentration, accurately expressed by the equation

$$\Lambda_M = a + b\Gamma \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a and b are constants for each electrolyte.

To avoid confusion, the units adopted by KOHLRAUSCH will be referred to as volume units and the units here proposed as mass units.

If the data for concentrated solutions of good electrolytes given by KOHLRAUSCH and HOLBORN be translated from volume units into mass units, and Λ_M be plotted against Γ, straight lines are obtained in almost every case. Fig. 1 shows the graphs obtained in this way for HNO_3, H_2SO_4, KOH, NaCl, and for comparison the corresponding graphs in volume units. The graphs obtained by using volume units are in thin lines and those obtained by using mass units in thick lines. It is important to notice that $\gamma = \frac{\eta}{s}$ and $\Lambda_M = \Lambda s$, so that the adoption of mass units instead of volume units does not affect the numerical statement of the relationships which have been established for dilute solutions: for when $s = 1$, as is practically the case in solutions more dilute than 0·1 normal, γ coincides with η and Λ_M with Λ. In such dilute solutions, whether we refer to unit volume of the solution or to unit volume of the solvent, or to unit mass of the solution or to unit mass of the solvent, the numerical expression of the experimental values is practically the same.

But in concentrated solutions the difference between the volume of a given solution and the sum of the volumes of the solvent and the solute taken separately often represents a very high internal pressure, and moreover this internal pressure varies greatly from one electrolyte to the other, so that, by taking equivalent quantities in equal volumes, we by no means establish comparable conditions. Even in an ideal case of a solution of a binary electrolyte without any such internal pressure, the concentration must be of the order of $\frac{1}{20}$ normal or less, if the condition of the solute in the solution is to be at all comparable with that of a gas at ordinary pressure. There appears therefore no logical reason in favour of volume units as against mass units, and, as stated above, the expression for the relationship between the concentration and conductivity becomes at once more simple and more useful when the mass units are adopted instead of volume units.

In order to test the applicability of equation (1) as closely as possible, the data given by KOHLRAUSCH and HOLBORN for concentrated solutions of good electrolytes, in so far as they are sufficient for the purpose, were translated from volume units into mass units, and from the new data thus obtained the constants a and b of equation (1) were calculated by the method of least squares. The results of these calculations are given in Table A, along with the data from which they are derived.

The several columns are as follows :—

I. The formula of the electrolyte and also the values for the constants of equation (1).
II. The percentages, *i.e.* the number of parts by weight of the electrolyte in 100 parts of the solution. Interpolated points are indicated in this column by parentheses. Experimental numbers excluded from the calculation of the constants are marked †. Older values to which KOHLRAUSCH attributes less exactness are marked.*
III. m., *i.e.* gramme equivalents per litre ($m = 1000\ \eta$).
IV. κ, *i.e.* specific conductivity in ohms^{-1} c.m.$^{-1}$.
V. $\Lambda = \frac{\kappa}{\eta}$, *i.e.* equivalent conductivity.
VI. Γ, *i.e.* gramme equivalents of electrolyte per kilogramme of the solution ($\Gamma = 1000\ \gamma$).
VII. $\Lambda_M = \frac{\kappa}{\gamma}$, *i.e.* specific conductivity divided by the number of equivalents per gramme of the solution.
VIII. As in column VII., but calculated from equation (1).
IX. Percentage differences between Λ_M observed and Λ_M calculated.
X. As in column IX., but for points outside the range within which equation (1) applies.
XI. As in column IX., but for interpolated points.

This arrangement of the percentage differences in three columns facilitates a review of the evidence for or against the applicability of equation (1).

TABLE A.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
								Percentage Differences.		
								Λ_M calc. $-$ Λ_M obs.		
	p	$1000\ \eta$ $(m\ ;\ 1/v)$	$10^4\kappa$	$\Lambda = \frac{\kappa}{\eta}$	$1000\ \gamma$ (Γ)	Λ_M obs.	Λ_M calc.			
	%									
	5	0·691	690	99·9	0·671	103·0	101·9	...	− 1·1	...
KCl	10	1·427	1359	95·2	1·342	101·3	101·2	− 0·1	...	...
$a = 102{\cdot}6$	15	2·208	2020	91·5	2·011	100·4	100·5	+ 0·1	...	...
$b = -1{\cdot}067$	20	3·039	2677	88·1[1]	2·681	99·7	99·7	± 0·0	...	...
	21	3·213	2810	87·5	2·816	99·8	99·6	− 0·2	...	...
	5	0·948	918	96·8	0·934	98·2	98·1	− 0·1	..	..
NH_4Cl	10	1·923	1776	92·4	1·869	95·1	95·2	+ 0·1	...	...
$a = 101{\cdot}0$	15	2·924	2586	88·4	2·803	92·2	92·3	+ 0·1	...	...
$b = -3{\cdot}094$	20	3·952	3365	85·0	3·738	90·0	89·4	− 0·7	...	...
	25	5·003	4025	80·5	4·671	86·2	86·5	+ 0·4	...	...
	5	0·884	672	76·0	0·855	78·6	78·4	− 0·3	...	...
	10	1·830	1211	66·2	1·709	70·9	71·2	+ 0·4	...	...
NaCl	15	2·843	1642	57·8	2·564	64·1	64·1	± 0·0	...	...
$a = 85{\cdot}5$	20	3·924	1957	49·9	3·419	57·3	57·0	− 0·5	...	...
$b = -8{\cdot}34$	25	5·085	2135	42·0	4·274	50·0	49·9	− 0·2	...	...
	26	5·325	2151	40·4	4·444	48·4	48·4	± 0·0	...	...
	26·4	5·421	2156	39·8	4·512	47·8	47·9	+ 0·2	...	...

[1] In KOHLRAUSCH and HOLBORN stated as 88·9. The calculation of the values for Γ and Λ_M involved the recalculation of the corresponding values for m and Λ. Only three errors of calculation were thus incidentally discovered.

TABLE A—*continued.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	P	$1000\,\eta$ $(m\,;\,1/v)$	$10^4\kappa_{18}$	$\Lambda=\frac{\kappa}{\eta}$	$1000\,\gamma$ (Γ)	Λ_M obs.	Λ_M calc.	Percentage Differences. Λ_M calc. − Λ_M obs.		
	%									
	5†	1·209	733	60·6	1·177	62·3	59·7	...	− 4·1	...
LiCl	10	2·487	1218	49·0	2·354	51·8	51·7	− 0·2	...	...
$a=67·7$	20*	5·249	1676	31·9	4·708	35·6	35·7	+ 0·3	...	...
$b=-6·79$	30*	8·340	1399	16·78	7·062	19·8	19·7	− 0·5	...	...
	40*†	11·820	844	7·14	9·418	8·96	3·75	...	− 58·0	...
	5	0·501	389	77·7	0·480	81·2	80·6	− 0·7	...	...
$BaCl_2$	10	1·050	733	69·8	0·960	76·4	76·8	+ 0·5	...	...
$a=84·4$	15	1·652	1051	63·6	1·440	73·0	73·1	+ 0·1	...	...
$b=-7·84$	(20)	2·314	1331	57·5	1·921	69·3	69·3	...	...	± 0·0
	24	2·894	1534	53·0	2·304	66·6	66·3	− 0·5	...	...
	5	0·659	483	73·3	0·631	76·6	76·3	− 0·4	...	...
$SrCl_2$	10	1·379	886	64·3	1·261	70·3	70·6	+ 0·4	...	...
$a=82·0$	15	2·168	1231	56·8	1·892	65·1	64·9	− 0·3	...	...
$b=-9·04$	(20)	3·034	1495	49·3	2·523	59·3	59·2	...	...	− 0·3
	22	3·403	1583	46·5	2·775	57·0	56·9	− 0·2	...	...
	5	0·938	643	68·6	0·901	71·4	71·4	± 0·0	...	...
	10	1·957	1141	58·3	1·803	63·3	63·5	+ 0·3	...	...
$CaCl_2$	(15)	3·059	1505	49·2	2·704	55·7	55·6	...	...	− 0·2
$a=79·3$	20	4·253	1728	40·6	3·605	47·9	47·7	− 0·4	...	...
$b=-8·78$	25	5·545	1781	32·12	4·507	39·5	39·7	+ 0·5	...	...
	30†	6·945	1658	23·87	5·408	30·7	31·8	...	+ 1·1	...
	35†	8·468	1366	16·13	6·309	21·7	23·9	...	+ 10·1	...
	5	1·094	683	62·4	1·050	65·0	64·7	− 0·4	...	...
$MgCl_2$	10	2·281	1128	49·5	2·100	53·8	54·2	+ 0·7	...	...
$a=75·2$	20	4·942	1402	28·37	4·200	33·4	33·3	− 0·3	...	...
$b=-9·99$	30†	6·052	1061	13·18	6·301	16·84	12·26	...	− 27·1	...
	34†	9·434	768	8·14	7·142	10·75	3·86	...	− 64·1	...
	5†	0·831	526	63·3	0·795	66·2	61·4	...	− 7·3	...
$MnCl_2$	10	1·731	844	48·8	1·590	53·2	52·9	− 0·6	...	...
(Long, 1880)	15	2·712	1055	38·9	2·383	44·3	44·6	+ 0·7	...	...
$a=69·8$	20	3·784	1134	30·0	3·179	35·7	36·1	+ 1·1	...	...
$b=-10·61$	25	4·954	1090	22·00	3·972	27·43	27·70	+ 1·0	...	...
	28	5·707	1016	17·80	4·448	22·83	22·65	− 0·8	...	...
	5	0·435	465	106·9	0·420	110·7	110·2	− 0·5	...	...
KBr	10	0·902	928	102·9	0·840	110·5	111·2	+ 0·6	...	...
(Kohlrausch, 1879)	20	1·945	1907	98·1	1·679	113·6	113·2	− 0·4	...	...
$a=109·2$	30	3·162	2923	92·4	2·518	116·0	115·2	− 0·7	...	...
$b=+2·396$	36	3·990	3507	87·9	3·023	116·0	116·4	+ 0·3	...	...
	5	0·312	338	108·3	0·301	112·3	111·5	− 0·7	...	...
KI	10	0·648	680	104·9	0·602	112·9	114·4	+ 1·3	...	...
	20*	1·407	1455	103·4	1·204	120·8	120·3	− 0·4	...	...
$a=108·5$	30*	2·301	2303	100·1	1·808	127·4	126·2	0·9	...	...
$b=+9·79$	40*	3·366	3168	94·1	2·410	131·4	132·1	+ 0·5	...	...
	55*†	5·401	4226	78·2	3·313	127·6	140·9	...	− 10·4	...

TABLE A—*continued.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	P	$1000\,\eta$ $(m\,;\,1/v)$	$10^4\kappa_{18}$	$\Lambda=\frac{\kappa}{\eta}$	$1000\,\gamma$ (Γ)	Λ_M obs.	Λ_M calc.	Percentage Differences. Λ_M calc. $-\Lambda_M$ obs.		
	%									
	10	0·735	772	105·1	0·690	112·0	112·9	+0·8	...	...
NH_4I *	20	1·573	1599	101·7	1·380	115·9	115·2	−0·6	...	...
$a=110·7$	(30)	2·538	2482	97·8	2·070	119·9	117·4	...	...	−2·1
$b=+3·259$	(40)	3·660	3393	92·7	2·760	122·9	119·7	...	...	−2·6
	50	4·973	4200	84·5	3·450	121·8	121·9	+0·1	...	...
	5	0·346	298	86·1	0·334	89·3	89·2	−0·1	...	...
NaI *	10	0·721	581	80·6	0·667	87·1	87·8	+0·8	...	...
$a=90·6$	20	1·566	1144	73·1	1·334	85·8	85·0	−0·9	...	...
$b=-4·165$	(30)	2·569	1653	64·3	2·001	82·5	82·2	...	...	−0·4
	40	3·778	2111	55·9	2·674	79·0	79·4	+0·5	...	...
	5	0·387	296	76·5	0·373	79·3	79·0	−0·4	...	...
LiI *	10	0·803	573	71·4	0·747	76·8	77·3	+0·7	...	...
$a=80·7$	(15)	1·252	838	66·9	1·120	74·8	75·5	...	...	+0·9
$b=-4·667$	20	1·739	1094	62·9	1·493	73·2	73·8	+0·8	...	...
	25	2·266	1346	59·4	1·867	72·1	72·0	−0·1	...	...
	5	0·894	652	72·9	0·859	75·9	75·9	±0·0	...	...
KF *	10	1·862	1209	64·9	1·718	70·4	70·3	−0·1	...	...
$a=81·5$	(20)	4·040	2080	51·5	3·435	60·6	59·1	...	...	−2·4
$b=-6·53$	(30)	6·554	2561	39·1	5·153	49·7	47·9	...	...	−3·6
	40	9·468	2522	26·6	6·870	36·7	36·7	±0·0	...	...
	10†	0·641	476	74·3	0·588	80·9	77·6	...	−4·1	...
	20	1·407	872	62·0	1·177	74·1	74·0	−0·2	...	...
	(25)	1·847	1058	57·3	1·471	71·9	72·1	...	...	+0·3
$AgNO_3$	(30)	2·332	1239	53·1	1·765	70·2	70·3	...	...	−0·2
$a=81·2$	(35)	2·872	1406	49·0	2·059	68·3	68·5	...	...	+0·3
$b=-6·18$	40	3·477	1565	45·0	2·353	66·5	66·7	+0·3	...	...
	(45)	4·158	1716	41·3	2·648	64·9	64·9	...	...	±0·0
	(50)	4·926	1856	37·7	2·942	63·1	63·1	...	...	±0·0
	(55)	5·791	1984	34·3	3·236	61·4	61·2	...	...	−0·3
	60	6·764	2101	31·1	3·530	59·6	59·4	−0·3	...	...
	5†	0·509	454	89·2	0·494	91·9	88·6	...	−3·6	...
KNO_3	10	1·051	839	79·8	0·988	84·8	84·5	−0·4	...	...
$a=92·8$	15	1·626	1186	72·9	1·482	80·0	80·4	+0·5	...	...
$b=-8·38$	20	2·240	1505	67·2	1·977	76·1	76·2	+0·1	...	...
	22	2·496	1625	65·1	2·174	74·7	74·6	−0·1	...	...
	5†	0·607	436	71·8	0·588	74·2	71·6	...	−3·5	...
$NaNO_3$	10	1·255	782	62·3	1·175	66·5	66·3	−0·3	...	...
$a=76·9$	20	2·688	1303	48·5	2·351	55·5	55·8	+0·6	...	...
$b=-8·95$	30	4·329	1606	37·1	3·526	45·6	45·3	−0·5	...	...
	5	0·699	438	62·7	0·674	65·1	64·6	−0·8	...	...
$Mg(NO_3)_2$	10	1·451	770	53·1	1·348	57·2	57·6	+0·7	...	...
$a=71·6$	(15)	2·260	1021	45·2	2·021	50·5	50·5	...	...	±0·0
$b=-10·45$	17	2·605	1102	42·3	2·290	48·1	47·7	−0·8	...	...

TABLE A—*continued.*

I.	II. P	III. 1000 η (m ; 1/v)	IV. $10^4\kappa_{18}$	V. $\Lambda=\frac{\kappa}{\eta}$	VI. 1000 γ (Γ)	VII. Λ_M obs.	VIII. Λ_M calc.	IX. Percentage Differences. Λ_M calc. − Λ_M obs.	X.	XI.
	%									
	5†	0·556	365	65·6	0·533	68·4	66·2	...	− 3·2	...
$Cu(NO_3)_2$	10	1·161	635	54·7	1·066	59·6	59·9	+ 0·5	...	...
(Long, 1880)	15	1·820	858	47·1	1·600	53·6	53·6	± 0·0	...	...
$a=72·5$	20	2·543	1018	40·0	2·131	47·7	47·4	− 0·6	...	...
$b=-11·83$	25	3·325	1089	32·8	2·664	40·9	41·1	+ 0·2	...	...
	35	5·136	1062	20·7	3·730	28·5	28·4	− 0·4	...	...
	10†	1·026	527	51·4	·945	55·8	53·9	...	− 3·4	...
$Sr(NO_3)_2$	15	1·604	690	43·0	1·417	48·7	48·2	− 1·0	...	...
$a=65·1$	20	2·233	802	35·9	1·890	42·4	42·6	+ 0·5	...	...
$b=-11·89$	25	2·920	866	29·66	2·361	36·7	37·0	+ 0·8	...	...
	35	4·478	861	19·23	3·310	26·0	25·7	− 1·2	...	...
	15†	1·039	429	41·4	0·906	47·5	45·8	...	− 3·4	...
$Pb(NO_3)_2$	20	1·455	521	35·8	1·208	43·1	42·8	− 0·7	...	...
$a=54·9$	25	1·916	600	31·3	1·511	39·7	39·8	+ 0·3	...	...
$b=-10·00$	30	2·422	668	27·6	1·813	36·9	36·8	− 0·3	...	...
	10†	0·921	513	55·7	0·847	60·5	59·5	...	− 1·7	...
	(15)	1·444	688	47·6	1·270	54·1	54·1	...	...	± 0·0
$Cd(NO_3)_2$	20	2·017	827	41·0	1·694	48·8	48·7	− 0·2	...	...
(Grotrian, 1883)	(25)	2·647	919	34·7	2·117	43·4	43·3	..	...	− 0·2
$a=70·3$	30	3·336	956	28·7	2·540	37·7	37·9	+ 0·5	...	...
$b=-12·75$	(35)	4·092	948	23·17	2·964	32·0	32·5	...	...	+ 1·6
	40	4·937 [1]	903	18·29 [2]	3·384	26·68	27·10	+ 1·1	...	...
	(45)	5·882	822	13·98	3·811	21·57	21·69	...	...	+ 0·5
	48	6·497	755	11·62	4·065	18·57	18·45	− 0·5	...	...
	4·67†	0·486	347	71·4	0·473	73·4	70·8	...	− 3·5	...
$KC_2H_3O_2$	9·33	0·995	625	62·8	0·951	65·7	65·5	− 0·3	...	...
$a=76·0$	28·00	3·276	1256	38·3	2·853	44·0	44·4	+ 0·9	...	...
$b=-11·08$	46·67	5·985	1122	18·75	4·753	23·61	23·38	− 0·9	...	...
	65·33†	9·128	479	5·25	6·656	7·20	2·30	...	− 68·0	...
K_2SO_4	...	0·5	391	78·2	0·484	80·8	80·7	− 0·1	...	...
$a=84·9$	5	0·596	458	76·8	0·573	79·8	79·9	+ 0·1	...	...
$b=-8·70$	...	1·0	718	71·8	0·938	76·6	76·7	+ 0·1	...	...
	10	1·240	860	69·4	1·147	75·0	74·9	− 0·1	...	...
	...	0·5	298	59·6	0·485	61·4	61·0	− 0·7	...	...
Na_2SO_4	5	0·735	409	55·6	0·703	58·1	58·1	± 0·0	...	...
$a=67·7$	...	1·0	508	50·8	0·943	53·9	54·7	+ 1·5	...	...
$b=-13·71$	10	1·536	687	44·7	1·407	48·8	48·4	− 0·8	...	...
	...†	2·0	800	40·0	1·789	44·7	43·3	− 1·0	...	...
	15†	2·411	886	36·7	2·110	41·9	38·7	...	− 7·6	...
	5†	0·778	552	71·0	0·756	73·1	71·0	...	− 2·9	...
$(NH_4)_2SO_4$	10	1·601	1010	63·1	1·513	66·8	66·9	+ 0·1	...	...
(Kohlrausch)	20	3·377	1779	52·7	3·026	58·8	58·7	− 0·2	...	...
$a=75·1$	30	5·322	2292	43·1	4·537	50·6	50·5	− 0·2	...	...
$b=-5·41$	31	5·528	2321	42·0	4·690	49·5	49·7	+ 0·4	...	...

[1] In KOHLRAUSCH and HOLBORN stated as 4·922.

[2] In KOHLRAUSCH and HOLBORN stated as 18·35.

TABLE A—*continued.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	P	$1000\,\eta$ $(m\,;\,1/v)$	$10^4\kappa_{18}$	$\Lambda=\frac{\kappa}{\eta}$	$1000\,\gamma$ (Γ)	Λ_M obs.	Λ_M calc.	Percentage Differences. Λ_M calc. − Λ_M obs.		
	%									
$(NH_4)_2SO_4$	...†	1·0	681	68·1	0·965	70·6	68·3	...	− 3·2	...
(Klein, 1886)	...	1·5	941	62·7	1·425	66·0	66·1	+ 0·1	...	...
$a=73·0$	...	2·0	1201	60·0	1·869	64·2	63·9	− 0·5	...	...
$b=-4·860$	...	2·5	1414	56·6	2·303	61·4	61·8	+ 0·7	...	...
	...	3·0	1630	54·3	2·720	59·9	59·8	− 0·2	...	...
	5†	0·873	263	30·1	0·831	31·6	28·9	...	− 8·5	...
	10†	1·836	414	22·55	1·661	24·92	24·14	...	− 3·1	...
	...	2·0	436	21·5	1·798	23·92	23·37	...	− 2·3	...
$MgSO_4$	..	2·5	467	18·68	2·194	21·29	21·10	− 0·9	...	...
$a=33·63$	15	2·891	480	16·60	2·491	19·26	19·41	+ 0·8	...	...
$b=-5·71$	...	3·423	493	14·40	2·884	17·09	17·16	+ 0·4	...	...
	(20)	4·054	476	11·74	3·322	14·32	14·66	...	...	+ 2·2
	...	4·108	483	11·76	3·362	14·37	14·43	+ 0·4	...	...
	25	5·342	415	7·77	4·153	9·99	9·92	− 0·7	...	...
	5	0·651	191	29·3	0·620	30·80	29·32	...	− 4·8	...
$ZnSO_4$	10	1·371	321	23·42	1·239	25·90	25·86	− 0·2	...	...
$a=32·79$	15	2·169	415	19·13	1·858	22·34	22·40	+ 0·3	...	...
$b=-5·59$	(20)	3·053	468	15·33	2·478	18·90	18·93	...	...	+ 0·2
	25	4·040	480	11·88	3·097	15·50	15·47	− 0·2	...	...
	(30)	5·124	444	8·66	3·717	11·95	12·01	...	...	+ 0·5
	5†	0·658	189	28·7	0·626	30·2	28·7	...	− 5·0	...
$CuSO_4$	10	1·387	320	23·1	1·253	25·6	25·6	± 0·0	...	...
$a=31·83$	15	2·194	421	19·19	1·880	22·40	22·44	+ 0·2	...	...
$b=-4·996$	17·5	2·631	458	17·41	2·192	20·90	20·88	− 0·1	...	...
	...†	1·476	315	21·34	1·344	23·44	23·00	...	− 1·9	...
$MnSO_4$	...	2·034	372	18·29	1·793	20·75	20·71	− 0·2	...	...
(Klein, 1886)	...	3·231	433	13·40	2·668	16·23	16·23	± 0·0	...	...
$a=29·88$	...	4·257	425	9·98	3·337	12·74	12·81	+ 0·5	...	...
$b=-5·12$	...	5·321	383	7·20	3·971	9·65	9·56	− 0·9	...	..
	...†	6·639	300	4·52	4·680	6·41	5·92	...	− 7·6	...
	5†	0·504	146	29·0	0·481	30·4	28·3	...	− 6·9	...
	10	1·060	247	23·3	0·961	25·7	25·7	± 0·0	...	...
$CdSO_4$	(15)	1·674	325	19·42	1·442	22·54	23·10	...	...	+ 2·5
(Grotrian, 1883)	(20)	2·354	388	16·48	1·922	20·18	20·50	...	...	+ 1·5
$a=30·91$	25	3·112	430	13·82	2·403	17·90	17·90	± 0·0	...	...
$b=-5·42$	(30)	3·958	436	11·02	2·884	15·12	15·30	...	...	+ 1·1
	(35)	4·902	424	8·65	3·363	12·61	12·70	...	...	+ 0·7
	36	5·102	421	8·25	3·460	12·16	12·17	+ 0·1	...	...
$FeSO_4$	...†	1	258	25·8	0·935	27·6	26·5	...	− 4·0	...
(Klein, 1886)	...	2	390	19·5	1·758	22·2	22·2	± 0·0	...	...
$a=31·37$	...	3	461	15·37	2·496	18·47	18·39	− 0·4	...	...
$b=-5·20$	...	3·56	470	13·21	2·880	16·32	16·39	+ 0·4	...	...
	...†	0·5	153	30·6	0·482	31·8	29·7	...	− 6·6	...
$NiSO_4$	...	1·0	254	25·4	0·929	27·3	27·1	− 0·7	...	...
$a=32·51$	...	2·0	385	19·25	1·738	22·14	22·35	+ 1·0	...	...
$b=-5·85$	...	3·0	452	15·07	2·455	18·41	18·15	− 1·4	...	...

TABLE A—*continued.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
	P	$1000\,\eta$ $(m\,;\,1/v)$	$10^4\kappa_{18}$	$\Lambda=\frac{\kappa}{\eta}$	$1000\,\gamma$ (Γ)	Λ_M obs.	Λ_M calc.	Percentage Differences. Λ_M calc. − Λ_M obs.		
	%									
	5	0·756	561	74·2	0·723	77·5	77·4	− 0·1	...	...
	10	1·579	1038	65·7	1·446	71·7	72·2	+ 0·7	...	...
K_2CO_3	20	3·448	1806	52·4	2·892	62·5	61·9	− 1·0	...	...
$a=82·5$	30	5·641	2222	39·4	4·338	51·2	51·5	+ 0·6	...	...
$b=-7·15$	40†	8·198	2168	26·45	5·784	37·48	41·16	...	+ 9·8	...
	50†	11·157	1469	13·16	7·230	20·30	30·81	...	+ 51·8	...
	5†	0·380	821	...	0·367	223·7	219·0	...	− 2·1	...
	10	0·787	1528	...	0·734	208·2	208·6	+ 0·2	...	...
$KHSO_4$	(15)	1·224	2178	...	1·101	197·8	198·1	...	...	+ 0·2
$a=229·5$	20	1·691	2769	...	1·468	188·6	187·6	− 0·5	...	...
$b=-28·52$	(25)	2·188	3256	...	1·835	177·4	177·2	...	...	− 0·1
	27	2·400	3419	...	1·982	172·5	173·0	+ 0·3	...	...
	10	1·606	727	45·3	1·467	49·6	48·1	...	− 3·0	...
$ZnCl_2$ (Long, 1880)	20	3·493	912	26·1	2·934	31·1	33·9	...	+ 9·0	...
$a=62·4$	30	5·720	926	16·19	4·404	21·0	19·6	...	− 6·7	...
$b=-9·711$										
$CdCl_2$	20†	2·626	299	11·39	2·187	13·68	11·45	...	− 16·3	...
(Grotrian, 1883)	30	4·365	282	6·47	3·281	8·60	8·42	...	− 2·1	...
$a=17·52$	40	6·508	221	3·40	4·374	5·06	5·38	...	+ 6·3	...
$b=-2·775$	50	9·185	137	1·49	5·468	2·50	2·35	...	− 6·0	...
$CdBr_2$	10†	0·802	164	20·4	0·735	22·3	19·6	...	− 12·1	...
(Grotrian, 1883)	20	1·764	236	13·4	1·471	16·1	16·1	± 0·0	...	...
$a=23·05$	30	2·934	273	9·30	2·206	12·4	12·6	+ 1·6	...	...
$b=-4·719$	43	4·892	261	5·34	3·162	8·26	8·13	− 1·5	...	...
	10†	0·595	103·9	17·5	0·547	19·0	18·5	...	− 2·6	...
	15	0·934	146	15·6	0·820	17·8	17·8	± 0·0	...	...
CdI_2	20	1·306	186	14·2	1·093	17·0	17·0	± 0·0	...	...
(Grotrian, 1883)	(25)	1·716	222	12·9	1·367	16·2	16·2	...	...	± 0·0
$a=20·08$	30	2·170	254	11·7	1·640	15·5	15·5	± 0·0	...	...
$b=-2·819$	(35)	2·680	282	10·5	1·914	14·7	14·7	...	...	± 0·0
	40	3·241	303	9·35	2·187	13·9	13·9	± 0·0	...	...
	45†	3·874	314	8·11	2·460	12·8	13·2	...	+ 3·1	...
KHS	15·08†	2·274	1928	84·8	2·088	92·3	106·5	...	+ 13·3	...
(Bock, 1887)	33·43	5·780	3749	64·7	4·630	81·0	81·1	+ 0·1	...	...
$a=127·4$	39·22	6·748	3982	59·0	5·432	73·3	73·1	− 0·3	...	...
$b=-10·00$	51·22	9·381	4003	42·7	7·094	56·4	56·5	+ 0·2	...	...
K_2S	24·64†	5·444	4401	80·8	4·467	98·5	101·0	...	+ 2·5	...
(Bock, 1887)	29·97	6·889	4563	66·2	5·436	83·9	84·3	+ 0·5	...	...
$a=177·9$	38·08	9·319	4106	44·1	6·902	59·5	59·1	− 0·7	...	...
$b=-17·22$	47·26	12·504	2579	20·63	8·566	30·1	30·4	+ 1·0	...	...
	2·02	0·529	612	115·7	0·518	118·2	116·7	− 1·3	...	...
Na_2S	5·03	1·359	1321	97·2	1·287	102·6	103·6	+ 1·0	...	...
(Bock, 1887)	9·64	2·736	2017	73·7	2·464	81·8	83·5	+ 2·1	...	...
$a=125·5$	14·02	4·163	2359	56·7	3·594	65·7	64·3	− 2·1	...	...
$b=-17·05$	16·12	4·873	2243	46·0	4·126	54·3	55·2	+ 1·6	...	...
	18·15	5·647	2184	38·7	4·645	47·1	46·4	− 1·4	...	...

TABLE A—*continued.*

Hydrates.

I.	II. P	III. 1000 η (m ; $1/v$)	IV. $10^4\kappa_{18}$	V. $\Lambda=\frac{\kappa}{\eta}$	VI. 1000 γ (Γ)	VII. Λ_M obs.	VIII. Λ_M calc.	IX. Percentage Differences. Λ_M calc. $-\Lambda_M$ obs.	X.	XI.
	%									
	4·2†	0·777	1464	188·4	0·748	195·6	198·8	...	+1·6	...
KOH	8·4	1·612	2723	168·9	1·496	182·0	183·0	+0·5	...	...
$a=214·6$	16·8	3·467	4558	131·5	2·992	152·4	151·3	−0·7	...	...
$b=-21·14$	25·2	5·583	5403	96·8	4·488	120·4	119·7	−0·2	...	...
	33·6	7·978	5221	65·4	5·984	87·2	88·1	+1·0	...	...
	42·0	10·695	4212	39·4	7·480	56·3	56·5	+0·4	...	...
	2·5	0·641	1087	169·6	0·624	174·3	174·2	−0·1	...	...
NaOH	5·0	1·319	1969	149·3	1·248	157·8	157·8	±0·0	...	...
$a=190·5$	10·0	2·779	3124	112·4	2·496	125·1	125·1	±0·0	...	...
$b=-26·22$	(15)	4·381	3463	79·0	3·744	92·4	92·4	...	...	±0·0
	20·0†	6·122	3270	53·4	4·992	65·5	59·6	...	−10·5	...
	1·25†	0·527	781	148·2	0·520	150·2	146·1	...	−2·7	...
LiOH*	2·5	1·069	1416	132·5	1·040	136·2	136·1	−0·1	...	...
$a=156·1$	5·0	2·194	2396	109·2	2·080	115·2	116·2	+0·9	...	...
$b=-19·23$	7·5	3·371	2999	89·0	3·120	96·2	96·2	±0·0	...	...

Acids.

	6·2	1·017	3123	307·1	0·983	317·5	316·3	−0·4	...	...
HNO_3	12·4	2·108	5418	257·0	1·967	275·4	276·5	+0·4	...	...
$a=356·0$	(18·6)	3·276	6901	210·7	2·950	233·9	236·8	...	...	+1·2
$b=-40·40$	24·8	4·533	7676	169·3	3·935	195·1	197·0	+1·0	...	...
	31·0	5·873	7819	133·1	4·917	159·0	157·4	−1·0	...	...
	10	2·176	3915	179·9	2·039	192·0	197·4	...	+2·8	...
	15	3·376	5432	160·9	3·059	177·6	178·3	+0·4	...	...
	20	4·655	6527	140·2	4·077	160·1	159·3	−0·5	...	...
$\frac{1}{2}H_2SO_4$	25	6·019	7171	119·2	5·096	140·7	140·2	−0·4	...	...
$a=235·5$	30	7·468	7388	98·9	6·116	120·7	121·1	+0·5	...	...
$b=-18·70$	35	9·011	7243	80·4	7·137	101·5	102·0	+0·5	...	...
	40	10·649	6800	63·8	8·155	83·4	83·0	−0·5	...	...
	(45)	12·396	6164	49·7	9·177	67·2	63·9	...	...	−4·9
	50	14·258	5405	39·9	10·195	50·8	44·9	...	−11·6	...
	10	3·228	566	17·54	3·060	18·50	18·65	+0·8	...	...
$\frac{1}{3}H_3PO_4$	(15)	4·976	850	17·08	4·590	18·52	18·43	...	...	−0·5
$a=19·08$	20	6·824	1129	16·56	6·120	18·45	18·22	−1·2	...	−
$b=-0·1406$	(25)	8·776	1402	15·98	7·650	18·32	18·00	...	...	−1·7
	30	10·840	1654	15·26	9·182	18·01	17·79	−1·2	...	...
	35	13·023	1858	14·27	10·710	17·35	17·57	+1·3	...	...

Table B.

(*Constant a.*)

	Li	Na	Ag	K	NH_4	Mg	Ca	Sr	Ba	Mn	Fe	Ni	Cu	Zn	Cd	Pb
F	...	...	...	81·5	...	...	...	...	...	...	...	...	...	...	...	...
Cl	68	86	...	103	101	75	79	82	84	70	...	...	...	...	...	...
Br	...	...	...	109·0	...	...	...	...	...	...	...	...	...	...	23	...
I	81	91	...	109	111	...	...	...	...	...	...	...	...	...	20	...
NO_3	...	77	81	93	97	72	...	65	...	...	...	...	73	...	70	55
$C_2H_3O_2$	...	47	...	76	...	...	...	...	...	...	...	...	...	...	...	...
SO_4	...	68	...	85	75	34	...	...	...	30	31	33	32	33	31	...
OH	156	191	...	215	...	...	...	...	...	...	...	...	...	...	...	...
SH	...	...	...	127	...	...	...	...	...	...	...	...	..	...	...	...
S	...	126	...	178	...	...	...	...	...	...	...	...	...	...	...	...
HSO_4	...	...	...	230	...	...	...	...	...	...	...	...	...	...	...	...

Table C.

(*Constant b.*)

	Li	Na	Ag	K	NH_4	Mg	Ca	Sr	Ba	Mn	Fe	Ni	Cu	Zn	Cd	Pb
F	...	...	...	−6·5	...	...	...	...	...	...	...	...	..	...	...	...
Cl	−6·8	−8·3	...	−1·1	−3·1	−10·0	−8·8	−9·0	−7·8	−10·6	...	...	...	...	...	...
Br	...	...	...	+2·4	...	...	...	...	...	...	...	...	...	...	−4·7	...
I	−4·7	−4·2	...	+9·8	+3·3	...	...	...	...	...	...	...	...	...	−2·8	...
NO_3	...	−9·0	−6·2	−8·4	...	−10·5	...	−11·9	...	...	...	...	−11·8	..	−12·8	−10·0
$C_2H_3O_2$	...	...	...	−11·1	...	...	...	...	...	...	...	...	...	...	...	...
SO_4	...	−13·7	...	−8·7	−5·4	−5·7	...	...	...	−5·1	−5·2	−5·9	−5·0	−5·6	−5·4	...
OH	−19·2	−26·2	...	−21·1	...	...	...	...	...	...	...	...	...	...	...	...
SH	...	...	...	−10·0	...	...	...	..	...	...	...	...	...	...	...	...
S	...	−17·1	...	−17·2	...	..	...	.	...	...	...	...	...	...	...	...
HSO_4	...	...	...	−28·5	...	...	...	...	...	...	...	...	...	...	...	...

Discussion of Results.

For a number of electrolytes sufficient data are not available. Sufficiently concentrated solutions are not attainable for sparingly soluble salts such as $Ba(NO_3)_2$, $KClO_3$, $LiCO_3$, etc., at least not for a temperature so low as 18° C. In other cases the deficiency of data is due to the fact that the concentrations were originally expressed in percentages. Thus for HCl there are determinations for 5 per cent., 10 per cent., 20 per cent., 30 per cent., and 40 per cent., but the corresponding equivalent concentrations are 1·405, 2·877, 6·034, 9·482.

Now the range within which equation (1) applies to HNO_3 is in equivalents per litre 1·017 to 5·873, and within this range there are only two points for HCl, so that further determinations are required to settle the question. Similar remarks apply to the data for NH_4NO_3, $Ca(NO_3)_2$, and $NaC_2H_3O_2$.

If equation (1) applies at all to solutions of weak electrolytes such as the organic acids and bases, the range of applicability is certainly small. Here also further data are required.

Data for forty-nine electrolytes are given in Table A. These include all the salts, strong acids, and strong bases for which sufficient data are given by Kohlrausch and Holborn.

$ZnCl_2$ and $CdCl_2$ stand out as marked exceptions. They are inserted along with $CdBr_2$ and CdI_2, in order to draw attention to the remarkable transition from $CdCl_2$, which is a decided exception through $CdBr_2$ with a very slightly curved graph, to CdI_2 which shows a perfect agreement between the observed and the calculated values for concentrations between 0·934 and 3·241 normal.

For the remaining 46 electrolytes the differences between the observed and the calculated values for Λ_M are given in column IX. Of these 185 differences, only 16 exceed 1 per cent., and none exceed 2·1 per cent. Of the 16 differences which exceed 1 per cent., 5 belong to Na_2S, and these five moreover include the only differences which exceed 1·7 per cent.

It is not easy to fix a criterion by which the applicability of equation (1) can be judged, or to say how close the agreement ought to be, for it is difficult to come to a definite conclusion as to the limits of error of the original determinations. Kohlrausch and Maltby, in discussing the errors affecting such determinations, make the following statement: "Immerhin kann man ziemlich sicher schliessen dass Fehler von 1 per cent. nicht selten vorkommen, was auch von vornherein wahrscheinlich wird sobald man die Fehlerquellen betrachtet." They also suggest a comparison between the results obtained by different observers as one means of throwing light on the question.

Now for K_2SO_4, Na_2SO_4, $MgSO_4$, and $(NH_4)_2SO_4$ two sets of determinations are given by Kohlrausch and Holborn, the one set by Kohlrausch and the other by Klein.

In the case of the first three salts the number of the respective determinations is

too small to permit of each set being treated separately, and as it is consequently impossible to judge of their relative accuracy, equal weight was given to the several values when calculating the constants a and b for these salts.

The percentage differences for K_2SO_4 are remarkably small, showing a close agreement between the two sets of determinations.

In the case of $(NH_4)_2SO_4$ the two sets of determinations were treated separately, as they each include four points within the range of concentration to which equation (1) is in this case applicable, that is, from about 1·5 normal up to 5·528 normal, this being the highest concentration given. Within this range there is a satisfactory agreement between the calculated and the experimental values for Λ_M. The constants are not the same, however, in the two sets, so that the straight lines obtained by plotting Λ_M against Γ do not coincide. Were the constants a and b calculated from KOHLRAUSCH's more concordant determination applied to the four determinations by KLEIN, three of his determinations would appear too low.

Now there are two points, one ($\Gamma = 1{\cdot}513$) determined by KOHLRAUCSH, and the other ($\Gamma = 1{\cdot}425$) by KLEIN, which have very nearly the same concentration. Interpolating for $\Gamma = 1{\cdot}425$, and using the constants calculated from KOHLRAUSCH's determinations, Λ_M is 67·3, while KLEIN's observed value is 66·0, the difference being 2 per cent. Similarly, interpolating for $\Gamma = 1{\cdot}513$ and using the constants calculated from KLEIN's values, Λ_M is 65·6 while KOHLRAUSCH's observed value is 66·8. Here the difference is 1·8 per cent. The concentrations being nearly the same, there can be no doubt of the discrepancy. It is therefore clear that the limit of error must be at least 0·9 per cent. It is probably greater.

Interpolated Points.

Many of the values given by KOHLRAUSCH and HOLBORN were obtained by graphic interpolation and not directly from observation. A reference to Table A will show that these interpolated values, when translated into mass units, agree in most cases extremely well with those calculated by equation (1). Thus 6 out of the 9 values given for $AgNO_3$ (20 per cent. – 60 per cent.) are interpolated values, and the differences in no case exceed 0·3 per cent. This cannot be said, however, of the interpolated points for KF and $CdSO_4$.

As $\Lambda_M = \Lambda s$ and $\Gamma = \frac{m}{s}$, the relationship between equivalent conductivity and concentration may be expressed in volume units by the equation

$$\Lambda = \frac{a}{s} + \frac{b}{s^2} m \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This equation may be used in place of graphic interpolation for the ranges of concentration to which equation (1) applies.

Fig. 2 shows the graph for KF in volume units with KOHLRAUSCH's interpolations,

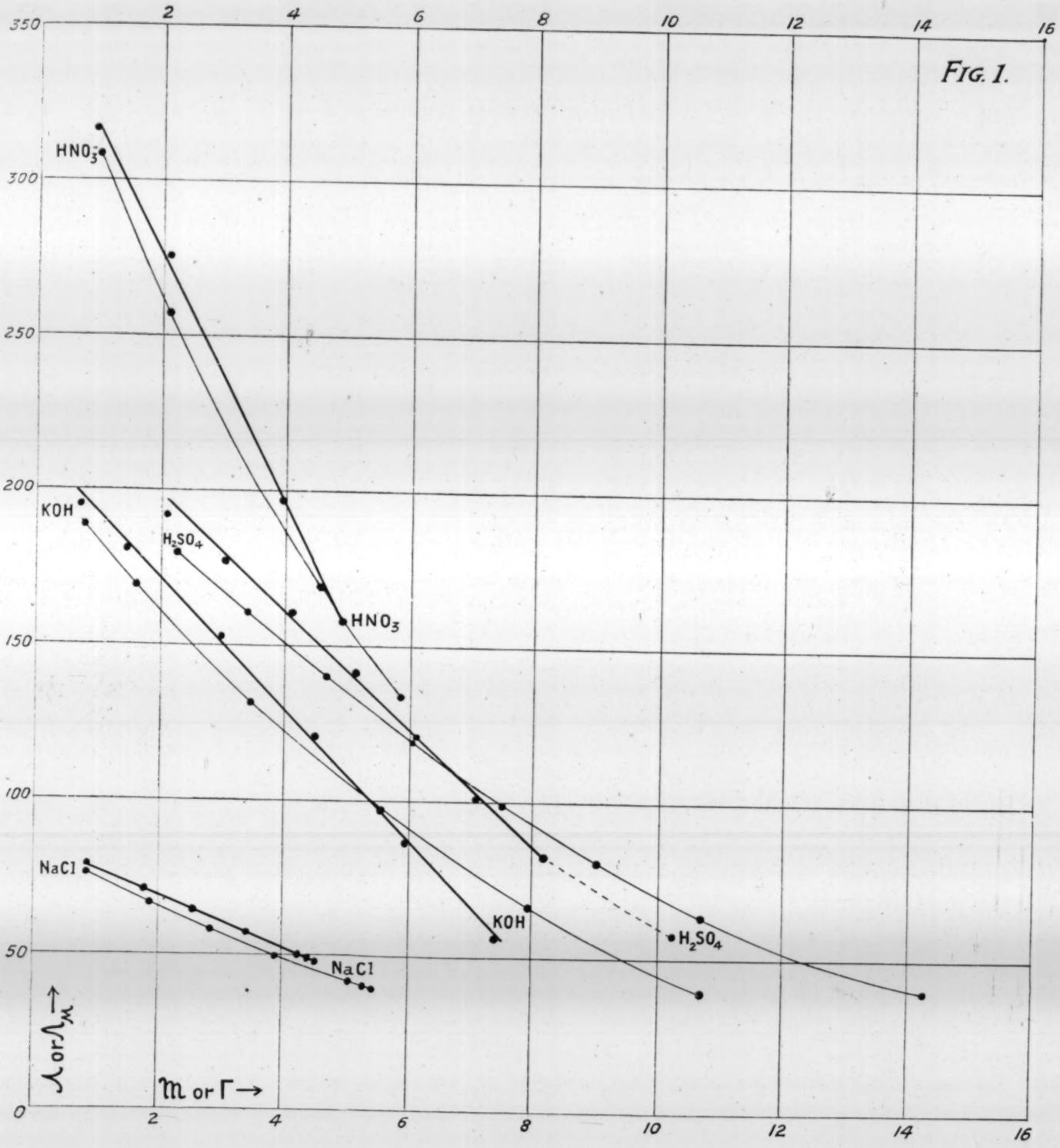
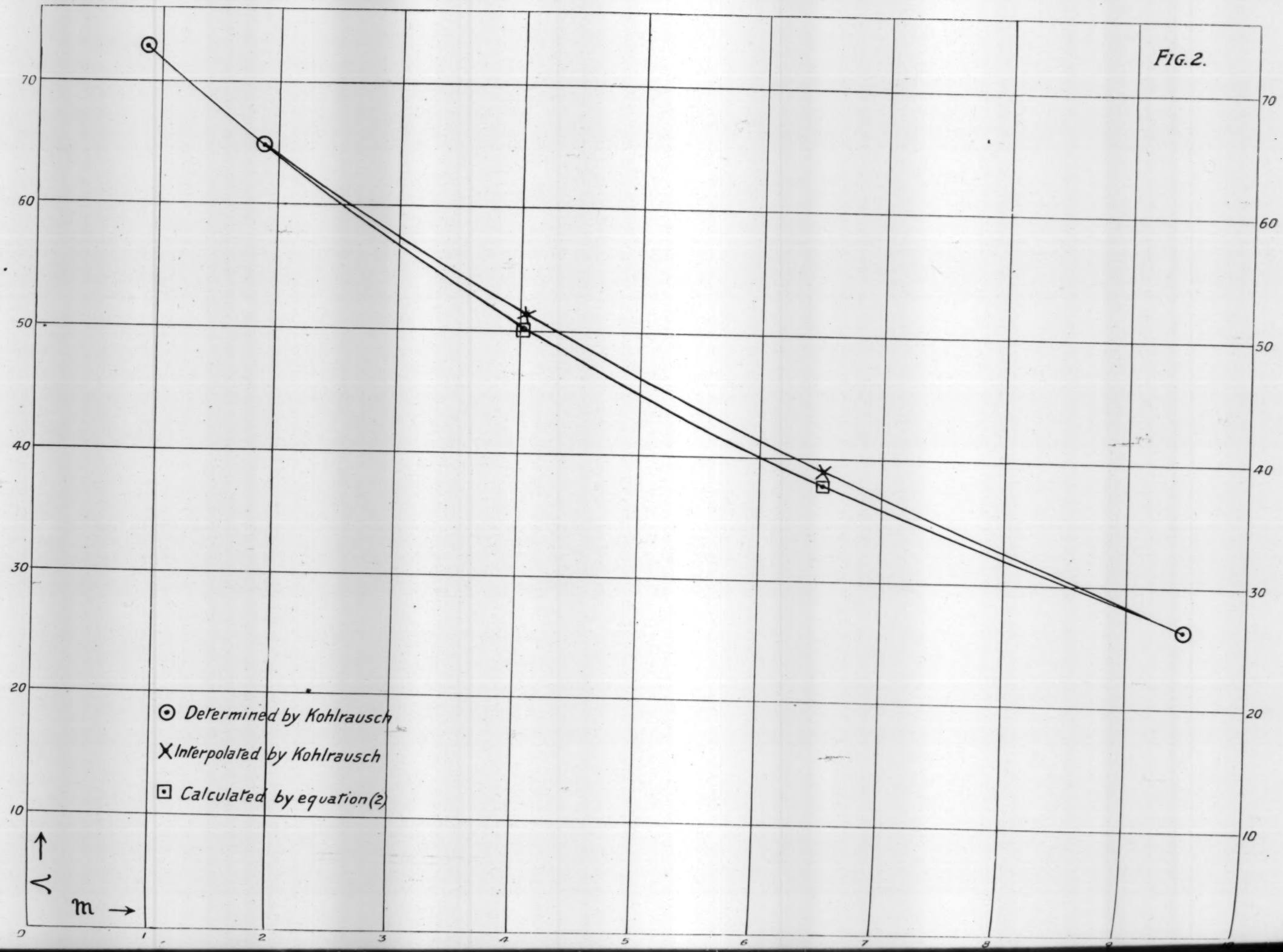


FIG. 1.
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
HNO3
KOH
H2SO4
HNO3
NaCl
KOH
H2SO4
NaCl
Λ or Λm →
m or Γ →

FIG. 2.


70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
Λ
m →
⊙ Determined by Kohlrausch
X Interpolated by Kohlrausch
⊡ Calculated by equation (2)

and for comparison the graph as interpolated by means of equation (2). Greater certainty in interpolation is clearly one of the advantages gained.

The Salts.

The graphs for a number of the salts given in Table A are shown in fig. 3. As in fig. 1 and fig. 4, the lines were calculated by equation (1), while the points indicate the experimental values. The agreement is, generally speaking, most satisfactory. As a rule the constant b is negative, so that Λ_M increases with the dilution. It is remarkable that in the case of KCl the constant b is only $-1{\cdot}067$, so that Λ_M varies very slightly with varying concentration. In the case of KBr, KI, and NH_4I the constant b is positive, that is, Λ_M decreases with dilution until a concentration of about 0·5 normal is reached. In solutions of these and of all the other electrolytes Λ_M rapidly increases on further dilution, and from about 0·1 normal down to infinite dilution the graphs practically coincide with those obtained by using the volume units. At a concentration of about 0·3–0·5 normal the values for Λ, for the salts generally, approximate very closely to the values for the constant a of equation (1).

The Hydrates.

The graphs for LiOH, NaOH, and KOH are shown in fig. 4.

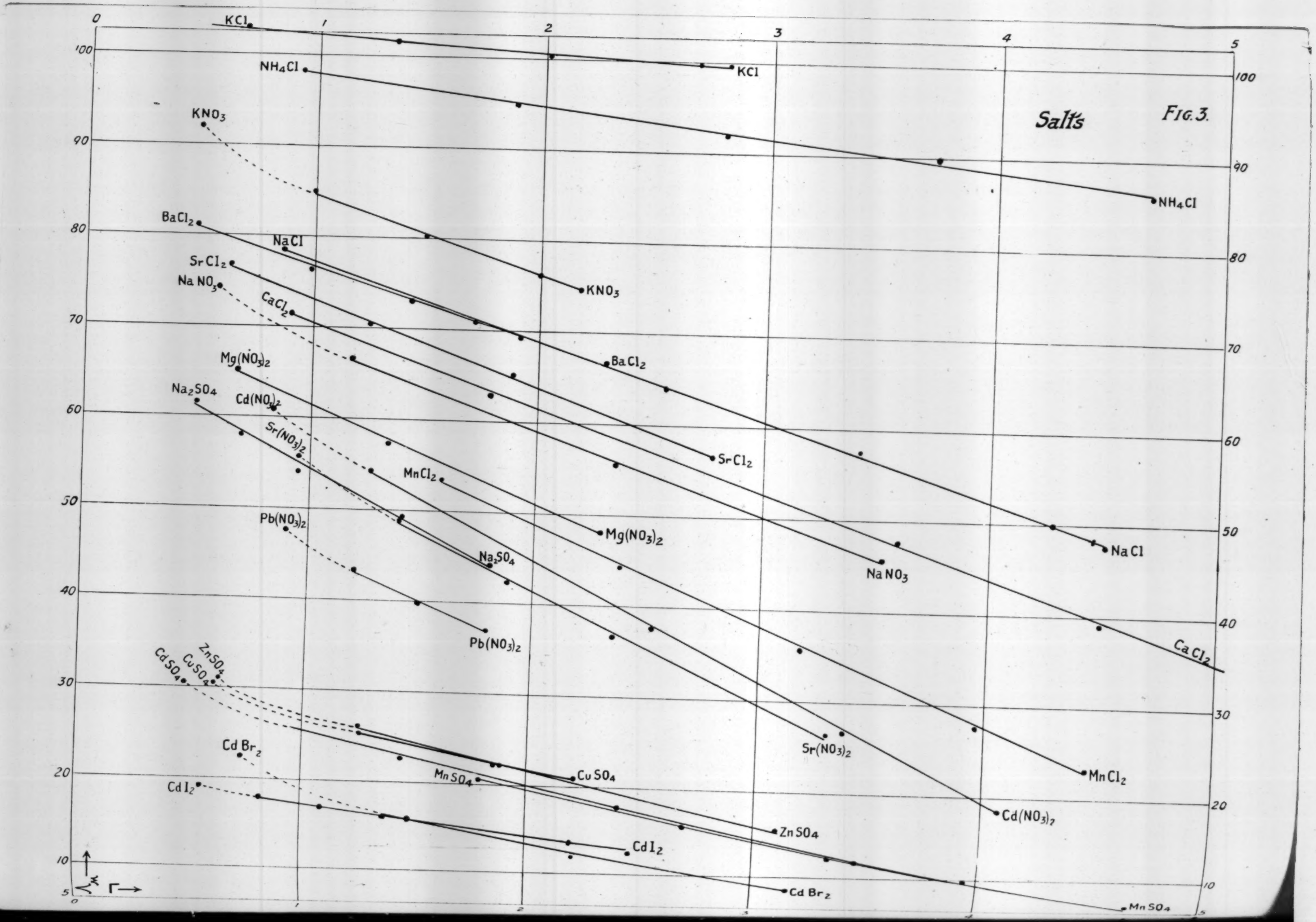
The data for LiOH and for NaOH are barely sufficient, but so far as they go, they point to a similar regularity. The graph for KOH is rectilinear over a very wide range of concentration, viz. from 1·612 normal to 10·695 normal, and the differences between the observed and calculated values for the five points given within this range in no case exceed 1 per cent., while for a concentration of 0·777 normal the difference is only $+1{\cdot}6$ per cent. In the case of NaOH the agreement between the experimental and the calculated values for Λ_M is perfect for the three points from 0·641 to 2·779 normal and also for the interpolated point 4·381 normal.

The only other point of higher concentration given, viz. that for 6·122 normal, is 10·5 per cent. out, so that the graph evidently becomes curved between 4·381 and 6·122 normal.

The Strong Acids.

The data for the halogen acids HCl, HBr, and HI are altogether insufficient.

An investigation into the conductivity of these acids will be published shortly. Meantime it may be stated provisionally that the determinations so far made show that equation (1) applies over considerable ranges of concentration to HBr and HI, and probably applies also in the case of HCl. The graphs for HNO_3, $\frac{1}{2}H_2SO_4$, and $\frac{1}{3}H_3PO_4$ are shown in fig. 4. The graph for $\frac{1}{3}H_3PO_4$ is remarkable for the very small variation in Λ_M over a wide range of concentration.


Salts
FIG. 3.
KCl
NH4Cl
KNO3
BaCl2
NaCl
SrCl2
NaNO3
CaCl2
Mg(NO3)2
Na2SO4
Cd(NO3)2
Sr(NO3)2
MnCl2
Pb(NO3)2
ZnSO4
CuSO4
CdSO4
CdBr2
MnSO4
CdI2
0
1
2
3
4
5
100
90
80
70
60
50
40
30
20
10
5

For nitric acid there are only four points given between 1 and 5·9 normal, but for these the greatest difference between the calculated and observed values is only + 1·1 per cent. At higher concentration the graph ceases to be even approximately linear.

The data for sulphuric acid are more complete. Six points, from 3·8 normal, show differences which do not exceed 0·5 per cent. As there is no indication of a trend in these differences, it is clear that equation (1) is applicable within this range. As in the case of nitric acid the graph ceases to be even approximately rectilinear at higher concentration. The data given are calculated for $\frac{1}{2}H_2SO_4$. Obviously they might have been calculated for $H(HSO_4)$. The advantages of this latter mode of representing the facts will be discussed in connection with the new data relating to the halogen acids.

The Constants of Equation (1).

Tables B and C show the manner in which anions and cations are grouped together according to the value of the constants a and b.

Certain groupings are clearly marked. The constants a for the chlorides, bromides, and iodides of potassium and ammonium agree closely. The isomorphous sulphates of Mg, Mn, Zn, Cd, Cu, and Fe show values for a and b which lie within narrow limits, viz., 30 to 34 for a, and 5·0 to 5·9 for b. In the case of the chlorides of Mg, Ca, Sr, and Ba the values for a rise in order from 75 for Mg to 83 for Ba, while conversely the values for b fall from −10 for Mg to −7·31 for Ba. These tables show clearly how much remains to be done before these relationships can be adequately discussed, but the data, though incomplete, justify the expectation that useful and general relationships will ultimately be established between the conductivity of concentrated solutions of good electrolytes and the character of their ions.

Some progress has been made towards filling up the gaps indicated by Tables B and C, but further discussion of these relationships must be postponed until some at least of these gaps have been filled up.

In a paper communicated to the Society in 1897, attention was drawn to increase in electrical conductivity as a characteristic of photo-chemical action, and in a second communication in December of the same year the following statement was made: "It would appear that the chemical behaviour of the acids just mentioned (HNO_3, HCl, H_2SO_4) depends in many of their reactions on whether their concentration is above or below that corresponding to their maximum electrolytic conductivity."*

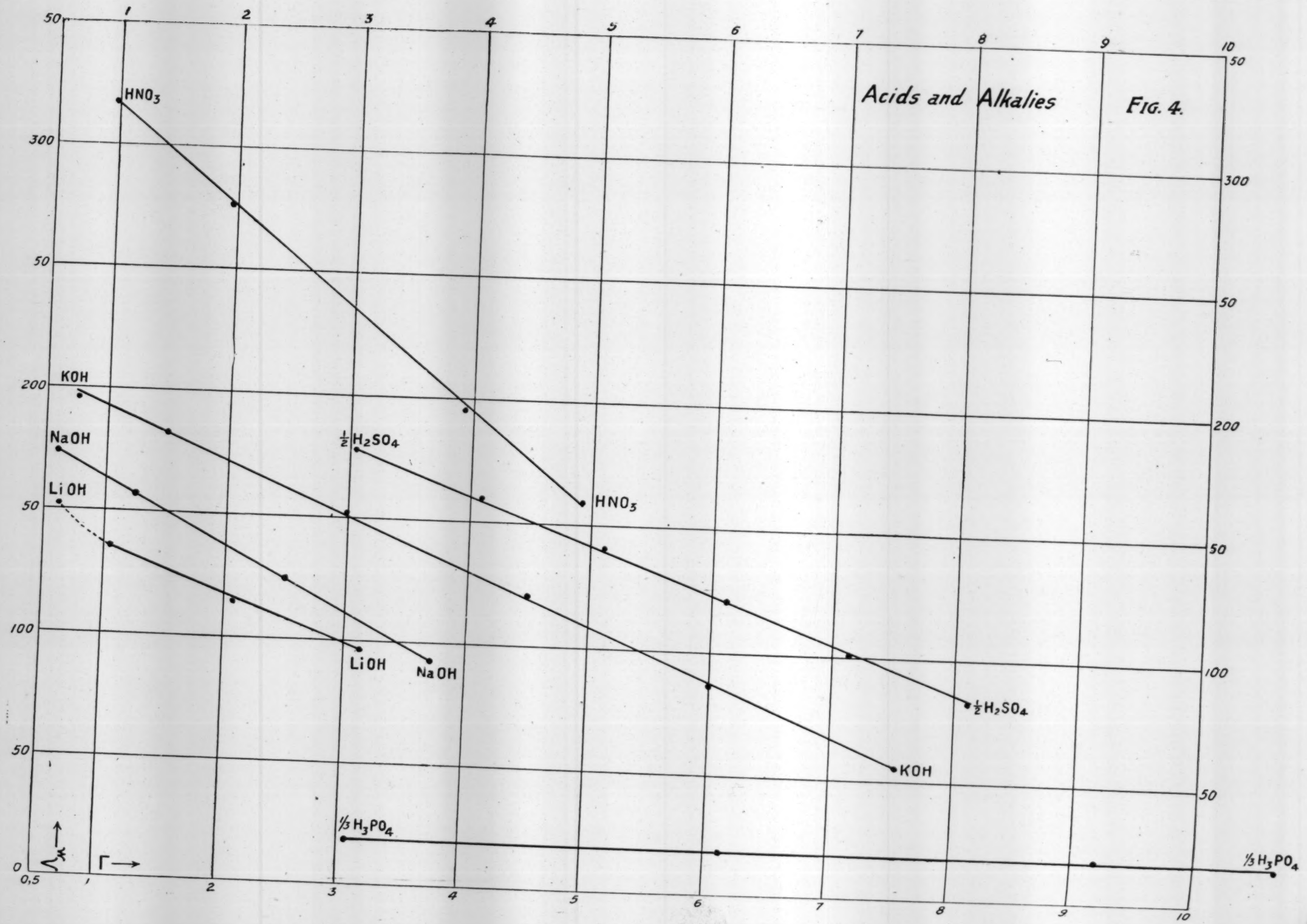
The exact experimental determination of the concentration corresponding to maximum specific conductivity is difficult, owing to the very slight variation of the conductivity with concentration near the maximum.

Now it is important to note that Table A shows clearly that in all cases where such

* κ = specific conductivity.

Acids and Alkalies

FIG. 4.



maxima are known to occur the corresponding concentration is included in the range within which equation (1) is applicable.

I am indebted to Mr G. E. GIBSON for pointing out that this in turn implies that in such cases the position of maximum conductivity may be calculated.

Thus equation (1) may be written

$$k = a\Gamma + b\Gamma^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

for a maximum $\frac{dk}{d\Gamma} = 0$. Hence by equation (3) the condition for maximum specific conductivity is

$$a + 2b\Gamma = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Hence the concentration at which the maximum occurs is $-\frac{a}{2b}$ gramme equivalents per kilogramme. Also by equation (3) the value of k at the maximum is $-\frac{a^2}{4b}$.

KOHLRAUSCH and HOLBORN (page 99) state that for sulphuric acid a maximum is reached "bei 30%," and for this percentage give $10^4k = 7388$ (page 156). The calculated values are 30·9 per cent. and $10^4k = 7414$.

The significance and importance of maximum electrolytic conductivity will be discussed in a subsequent communication. This paper is intended as a review of the data published hitherto.

In conclusion I desire to thank Professor MACGREGOR for kind and helpful criticism, and Mr ANDREW KING for valuable assistance in the calculations for Table A.

HERIOT WATT COLLEGE.

BRITISH
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MUSEUM

X.—Contributions to the Craniology of the People of the Empire of India. Part III.: Natives of the Madras Presidency, Thugs, Veddahs, Tibetans, and Seistanis. By Principal Sir Wm. Turner, K.C.B., D.C.L., F.R.S. (With Four Plates.)

(Read June 4, 1906. Issued separately July 26, 1906.)

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Introduction.

Since the publication in the *Transactions* of this Society of Part II. of my Contributions to Indian Craniology,* I have prepared for publication descriptions of additional series of skulls, both from India itself and from countries with which the Government of India has had diplomatic relations in recent years. From the Presidency of Madras I have obtained specimens of the Tamil-speaking Southern Dravidians, of Pariahs, and the skeleton of a Badaga. I have examined and described an interesting series of the skulls of the professional stranglers or Thugs. Some additional skulls of the Veddahs of Ceylon, with one of which the other bones of the skeleton had been preserved, have also been presented to the Anatomical Museum of the University. To former pupils attached as medical officers to the expeditions to Tibet and Seistan I am indebted for skulls from those countries. Thirty-nine specimens are described in this part, and their measurements are recorded in the tables.

MADRAS PRESIDENCY.

Tamil Sudras, Trichinopoly. Table I.

In July 1901 I received, through the courtesy of my friend Lieut.-Col. W. B. Bannerman, I.M.S., twelve skulls collected by direction of Lieut.-Col. W. A. Lee, I.M.S., in the native cemetery at Trichinopoly, near the banks of the river Cauvery, the burying-ground of the caste of the Tamil Sudra. They were of persons who

* Part I. of these Contributions appeared in the *Transactions*, vol. xxxix. part 3, 1899; Part II. in vol. xl. part 1, 1901.

had reached adult life, and two were aged. Seven were without doubt males, and five had female characters. As they showed a want of uniformity in the relations of the length and breadth of the cranium, and in the proportions of the nasal region, they cannot well be considered in a common description.

In general form and proportion two male skulls (A and B) were brachycephalic, the cephalic index being 83·2 and 80·8 respectively, whilst a third (C), with the index 79·1, so closely approached A and B that it should be placed along with them.

Norma verticalis.—A was rounded in outline; the vertex was somewhat flattened, and the slope outwards to the parietal eminences, which were distinct, was gentle; the side walls bulged somewhat, and the interparietal diameter was the widest part of the cranium. The parieto-occipital region was flattened, especially on the right side, as if local pressure, applied in infancy, had caused an obliquity. B and C were not so rounded in outline, they were broadly ovoid; the sagittal line was somewhat raised and the slope to the parietal eminences was steeper than in A. The side walls bulged somewhat, the parieto-occipital slope was steep though not so flattened as in A. In all three skulls the parieto-squamous diameter much exceeded the interzygomatic, and the stephanic was more than the asterionic diameter. The crania were cryptozygous.

Norma lateralis.—In all the crania the forehead receded slightly, the glabella and supraorbital ridges were moderate, the nasion was depressed in C but not in A and B. In A the parietal longitudinal arc was the shortest and the frontal exceeded the occipital; in B and C the parietal was the longest and the occipital the shortest. A and B rested behind on the cerebellar fossæ of the occiput, C on the mastoids.

Norma facialis.—The floor of the nose was separated by a sharp border from the incisive region, and the maxillo-nasal spine was moderate. The nasal region was narrow, and the bridge of the nose was moderately projecting and concave. The maxillary part of the face was relatively long. The upper jaw did not project forwards. The orbital borders were thicker in C than in A and B, and in it also the canine fossæ were deep and the infraorbital suture was present: the orbital apertures were low. The palato-maxillary arch was wide and horseshoe-shaped.

The cranial sutures were simple and not obliterated. No skull was metopic. In A the occipital squama was almost equally divided into a mesial and two lateral parts, but the suture between the mesial and right lateral had nearly disappeared. The basion had a mesial 3rd condyl and the lateral condyls were flattened; a right paracondylar process, the free end of which was smooth, as if articular, was present. In B the parietal and sphenoid scarcely articulated in the pterion, but in the other skulls their suture was broad. The teeth were for the most part lost, but when present were stained with betel.

The mean dimensions in the three crania were as follows: glabello-occipital length, 174 mm.; basi-bregmatic height, 140 mm.; parieto-squamous breadth, 141 mm.; horizontal circumference, 507 mm.; vertical transverse circumference, 436 mm.; longitudinal circumference, 499 mm. The crania were of moderate dimensions in ex-

BRITISH MUSEUM

Table I.

Trichinopoly—Tamil Sudras.

Edinburgh University Anatomical Museum.												
Collection number,	A.	B.	C.	D.	E.	F.	G.	H.	I.	K.	L.	M.
Age,	Ad.	Ad.	Ad.	Aged.	Ad.	Ad.	Ad.	Aged.	Ad.	Ad.	Ad.	Ad.
Sex,	M.	M.	M.	M.	M.	F.	F.	M.	F.	M.	F.	F.
Cubic capacity,	1290	1300	1380	1270	1255	1295	980	1240	1145	1320	1210	1305
Glabello-occipital length,	173	172	177	175	170	176	166	179	171	175	177	179
Basi-bregmatic height,	136	138	147	134	134	135	129	135	127	141	133	132
Vertical Index,	*78·6*	*80·2*	*83·1*	*76·6*	*78·8*	*76·7*	*77·7*	*75·5*	*74·3*	*80·6*	*75·1*	*73·7*
Minimum frontal diameter,	99	95	98	87	90	92	86	92	84	90	91	96
Stephanic diameter,	116	114	118	115	107	108	106	104	102	108	110	112
Asterionic diameter,	105	105	106	102	100	106	101	94	102	112	101	103
Greatest parieto-squamous breadth,	144p.	139s.	140s.	134s.	128p.	133s.	128	130p.	123s.	130p.	130p.	132p.
Cephalic Index,	*83·2*	*80·8*	*79·1*	*76·6*	*75·3*	*75·6*	*77·1*	*72·6*	*71·9*	*74·3*	*73·4*	*73·7*
Horizontal circumference,	502	508	512	500	482	498	476	497	475	494	498	503
Frontal longitudinal arc,	127	130	128	135	123	129	116	136	126	130	124	126
Parietal ,, ,,	111	131	137	120	127	129	116	122	128	125	126	128
Occipital ,, ,,	123	107	99	108	102	107	105	108	104	123	119	114
Total ,, ,,	361	368	364	363	352	365	337	366	358	378	369	368
Vertical transverse arc,	311	320	315	313	295	307	290	300	284	306	291	298
Basal transverse diameter,	120	119	124	119	115	115	112	115	106	120	111	110
Vertical transverse circumference,	431	439	439	432	410	422	402	415	388	426	402	408
Length of foramen magnum,	30	37	36	35	35	34	30	33	34	36	33	30
Basi-nasal length,	98	98	107	99	99	100	100	103	92	94	96	99
Basi-alveolar length,	...	91	100	96	93	96	98	97	89	90	...	...
Gnathic Index,	...	*92·9*	*93·5*	*97·*	*93·9*	*96·*	*98·*	*94·2*	*96·7*	*95·7*	...	...
Total longitudinal circumference,	489	503	507	497	486	499	467	502	484	508	498	497
Interzygomatic breadth,	126	126	130	131	126	121	116	128	115	121	117	115
Intermalar ,,	123	114	116	114	109	110	106	116	105	111	106	105
Nasio-alveolar length,	66ap.	68	68	71	57	64	62	61	56	59	...	...
Maxillo-facial Index,	*52·3*	*54·*	*52·3*	*54·2*	*45·2*	*52·8*	*53·4*	*47·6*	*48·7*	*48·7*	...	...
Nasal height,	52	51	49	55	44	48	43	48	41	46	48	46
Nasal width,	23	23	24	25	23	21	24	26	20	24	25	25
Nasal Index,	*44·2*	*45·1*	*49·*	*45·5*	*52·3*	*43·8*	*55·8*	*54·2*	*48·8*	*52·2*	*52·1*	*54·3*
Orbital width,	41	39	41	42	38	38	34	41	37	39	38	36
Orbital height,	32	31	34	31	29	33	33	32	30	28	31	30
Orbital Index,	*78·*	*79·5*	*82·9*	*73·8*	*76·3*	*86·8*	*97·1*	*78·*	*81·1*	*71·8*	*81·6*	*83·3*
Palato-maxillary length,	...	53	55	54	52	53	55	51	51	50	...	...
Palato-maxillary breadth,	70	61	66	...	55	...	60	65	58	63	...	...
Palato-maxillary Index,	...	*134·*	*120·*	...	*105·5*	...	*109·*	*127·*	*113·7*	*126·*	...	...
Nasio-Malar Index,*	*111·8*	*112·9*	*113·1*	*110·2*	*112·6*	*110·6*	*110·3*	*113·4*	*109·*	*107·4*	*109·6*	*110·8*

* The importance of measurements to determine the character of the profile of the nose was shown by Mr Oldfield Thomas (*Journ. Anthrop. Inst.*, vol. xiv. p. 332, 1885). From them a nasio-malar index may be computed as follows, the bi-malar line being = to 100; $\frac{\text{nasio-malar line} \times 100}{\text{bi-malar line}}$. The bi-malar line is the distance in a direct line between the most posterior points of the malar borders of the two orbits. The nasio-malar line I measured with sliding compasses between these points on the two malar bones and the mid-point of the nasion. A low, flat-faced profile is *platyopic*, say, with index below 106; a projecting profile is *pro-opic*, say, with index above 110; whilst one with intermediate projection is *mesopic*.

ternal measurements. In A and B the vertical index was less than the cephalic, but in C the height was more that the breadth. The mean vertical index was 80·6, hypsicephalic, and the mean length-breadth index was 81, brachycephalic. As the breadth-height index in A and B was less than 100, the index was platychamæcephalic.*

In each skull the jaw was orthognathous, the maxillo-facial index was leptoprosopic, the orbits were microseme, the palate was hyperbrachyuranic; the nasal index in two was leptorhine, in the third mesorhine. The nasio-malar index ranged from 111·8 to 113·1, and the mean was 112·6.

The intracranial capacity ranged from 1290 to 1380 c.c., and the mean of the series was 1323 c.c.

The other skulls (D to M), measured in Table I., had, as regards five, the cephalic index below 75, and were dolichocephalic; the remaining four ranged in the index from 75·3 to 77·1; they were in the lower term of the mesaticephalic group and were approximately dolichocephalic. They had reached adult life and two were aged. Four were males and five were apparently females.

Norma verticalis.—The crania were elongated and relatively narrow. In the females the parietal eminences were projecting. D and H were somewhat flattened at the vertex. In four crania the sagittal line was slightly raised and the slope downwards to the parietal eminences was well marked. The crania had a gradual slope downwards in the parieto-occipital region, which in some specimens was flattened from side to side: the occipital squama bulged a little backwards. The side walls as a rule were not bulging. In several crania the greatest parieto-squamous breadth only slightly exceeded the interzygomatic diameter. The stephanic was more than the asterionic diameter, except in one specimen where they were equal. The skulls were cryptozygous.

Norma lateralis.—In the males the forehead sloped gently backwards, the glabella and supraorbital ridges were moderate, and the nasion was a little depressed. In the females the forehead was nearly vertical, the supraorbital ridges were feeble, and the nasion was scarcely depressed. The bridge of the nose was usually short, it projected somewhat forwards and downwards, was as a rule concave, but in G, I, and L it had a tendency to flattening. In all the crania the occipital longitudinal arc was the shortest: in four the parietal arc was longer than the frontal, in two they were equal. Three crania rested behind on the mastoids, five on the cerebellar fossæ, one on the occipital condyls (Pl. VIII., figs. 37–39).

Norma facialis.—The floor of the nose was separated from the incisive region of the maxilla by a ridge which in some was sharp but in others was low and smooth. The maxillo-nasal spines were moderate. The upper jaw did not project forwards. In

* In my memoir on the Craniology of the People of Scotland (*Trans. Roy. Soc. Edin.* vol. xl. part iii. p. 599, 1903), I have specially referred to the relations of the breadth to the height of the cranium, and have computed a breadth-height index from the following formula: $\frac{\text{basi-bregmatic height} \times 100}{\text{parieto-squamous breadth}}$. When the index exceeds 100 the skull is *hypsistenocephalic*, a high, narrow skull; when less than 100, *platychamæcephalic*, a wide, low skull.

three the anterior nares were wide, in two they were narrower and more elongated, in four they were intermediate in character. The maxillary region of the face was moderately long. In several specimens the orbital borders were thickened, and in two the infra-orbital sutures were present. In E the canine fossæ were deep. The orbital apertures were usually low, but in one specimen the opening was rounded. The palato-maxillary arch was variable.

The cranial sutures were simple, but in three they were almost entirely obliterated, although in one of these indications of the frontal suture were visible. In all the parieto-sphenoid articulation was well marked. In four crania one or two small Wormian bones were in the lambdoid suture. There was no 3rd condyl, but in two crania the jugal processes were tuberculated.

In the group of nine skulls, dolichocephalic or approximating thereto, the mean dimensions of four males were: glabello-occipital, 174·7 mm.; basi-bregmatic, 136 mm.; greatest breadth, 130·5 mm.; horizontal circumference, 493·2 mm.; vertical transverse, 420·7; total longitudinal, 498·2 mm. Compared with the mean dimensions of the three brachycephalic males, the mean length and longitudinal circumference were almost alike in both groups, but the mean height, breadth, horizontal and vertical transverse circumference were distinctly greater in the brachycephali.

In the five female dolichocephali the mean corresponding dimensions were: length, 173·8; height, 131·2; breadth, 129·2; horizontal circumference, 490; vertical transverse circumference, 404·4; longitudinal circumference, 489·4 mm. In the mean length, breadth, and horizontal circumference the males did not much exceed the females, but in the male dolichocephalic group, the height, vertical transverse and longitudinal circumference were materially greater than in the females.

The intracranial capacity of the males ranged from 1240 to 1320 c.c., and the mean was 1271; the range in the females was from 980 to 1305, with a mean 1187 c.c. It is seldom that a woman's skull is less than 1000 c.c., though three Australians which I have measured were 930, 946, and 998 c.c. respectively.* Presumably in all such cases the stature had been low and the general physique feeble.

In this group of nine skulls the height in seven was more than the breadth, the vertical index was therefore greater than the cephalic, but in two skulls these indices were equal. The mean vertical index was 76·5, hypsicephalic; the mean cephalic index was 74·5, dolichocephalic. The breadth-height index in these skulls was above 100, and they were hypsistenocephalic.

As regards the mean proportions of the face the upper jaw was orthognathic, 95·9; the maxillo-facial index was leptoprosopic in three, mesoprosopic in four, and the mean, 50, was mesoprosopic; the nasal index was platyrhine in three, mesorhine in four, leptorhine in two, and the mean, 51, was mesorhine; the nasio-malar index ranged from 107·4 to 113·4, and the mean was 110·5, so that the nasal bridge projected moderately and the

* See my memoirs on Human Skulls and Skeletons in *Challenger Reports*, part xxix. p. 35, 1884, and part xlvii. p. 122, 1886.

face was mesopic; the orbits, microseme in seven, mesoseme in one, and megaseme in one, had a mean microseme or low index 81; the palato-maxillary arch ranged from elongated dolichuranic to short and very wide hyperbrachyuranic proportions, and the mean, 116, was brachyuranic.

Owing to the difference in form between the skulls marked A, B, C and those of dolichocephalic form and proportions, I applied for further information regarding the cemetery and the persons buried in it. In reply Colonel LEE writes that sometimes wandering beggars or bhairagis, who may die at Trichinopoly, are buried there, which may account for the presence of a few specimens of a different type. Further, he says that the only inhabitants of the city are the Dravidians and the Muhammadans; many of the latter are "pucka" Musalmans, others are Lubbais,* but they have separate burial-grounds.

As it is not possible to speak definitely of the race to which the three skulls possessing brachycephalic characters belonged, I can do little more than record their appearance and measurements. Obviously they were not Dravidians, and in all probability they were importations from outside sources, though it can scarcely be said that their facial characters associated them with the Mongoloid type.

As in Part II. of these Memoirs I have described a number of skulls of undoubted Dravidian tribes from the Central Provinces, and analysed their characters, a comparison may now appropriately be made between them and the Tamil skulls from Southern India. In both series the crania were elongated and dolichocephalic, an occasional skull having an index in the lower term of the mesaticephalic group; in both the nasal index was platyrhine or mesorhine, a leptorhine index being exceptional; in both the upper jaw was orthognathic, in the Tamils no skull was prognathous, and in the previous Dravidian series only one in thirty-six skulls had so high an index; in both the prevailing orbital index was low or microseme; in the previous series the mean maxillo-facial index was low or chamæprosopic, in the Tamils the mean index was somewhat higher and mesoprosopic; the palato-maxillary arch, though with a wide variation in each series, was in the mean brachyuranic; in both the cranial capacity was below the European average. The cranial configuration in both series therefore closely corresponded, and testified to their racial affinities.

PARIAHS. TABLE II.

Europeans have long recognised in Southern India people known as Pariah, Pareiyas, or Paraiyan, forming a low caste engaged in agriculture, domestic service, and various menial occupations. In the recent Census of India (1901) their number is given as 2,258,611,† of whom upwards of two millions are in Madras, and the remainder live in

* The Lubbais, variously spelt Labbeis, Lubbye, Lubbays, are people speaking Tamil, but Musalmans in religion, who are believed to be the descendants of Arabs who have intermarried with Dravidian native women.

† *Census of India*, vol. I. – A, by H. H. RISLEY and E. A. GAIT; part ii., Tables, pp. 303, 341. Calcutta, 1903.

Coorg, Burma, Cochin, and Travancore. Their language is Tamil, and they are Hindus in religion. Two classes have been distinguished amongst them,* (*a*) a primitive Dravidian people, who were perhaps the original inhabitants of the country, and in course of time lost their independence and became servile; Bishop CALDWELL states that they are† a well-defined, ancient caste which has its own subdivisions, usages, and traditions, and is jealous of the encroachments of the castes which are above and below it; (*b*) people who, or whose ancestors, had belonged to other and higher castes and had become degraded into a servile caste.

The collection formed by the Phrenological Society of Edinburgh, now part of the Henderson Trust, contains three skulls marked Pariah, Nos. 103–5. They were presented in 1828 by Sir G. S. MACKENZIE of Coul, and were procured at Madras by his son through the aid of a native, who took them from the burying-place of the caste.‡ They were all males, and had reached adult life. Some years ago the Rev. J. M. STRACHAN, M.D., of Madras, presented me with the skull of a Pariah which is now in the Anatomical Museum of the University. As the basi-cranial synchondrosis has barely completed its ossification, and the wisdom teeth are not erupted, the age was probably from 20 to 23. The lower jaw was absent in all the specimens, and the face was broken away in No. 104. The characters of the crania are summarised in the following description.

Norma verticalis.—The cranial outline was an elongated ovoid; the sagittal line was not ridged; the parietal eminences were well marked for male skulls; the slope downwards to them was steep in Nos. 103 and 104 but not in the others. In only one was the squamous region wider than the parietal. The parieto-occipital slope was gradual, there was no sign of artificial flattening, and the occipital squama bulged behind the inion. The crania were cryptozygous (Pl. VIII., figs. 40–42).

Norma lateralis.—The forehead was not retreating, the glabella and supraorbital ridges were moderate, though in Nos. 103 and 105 somewhat more projecting than in the others, and in them the nasion was depressed. The bridge of the nose was short, concave, and not flattened or rounded from side to side. In all the occipital longitudinal arc was the shortest, and in three the frontal longitudinal arc was longer than the parietal. Two skulls rested behind on the mastoids, and two on the cerebellar fossæ.

Norma facialis.—The nose was widely platyrhine, 61·9, in No. 103, but mesorhine in the other two. The floor of the nose was separated from the incisive region by a sharp ridge and the maxillo-nasal spine was moderate. The upper jaw was orthognathous in Nos. 103 and 48A, mesognathous in No. 105. The maxillo-facial index was leptoprosopic in No. 105, and mesoprosopic in Nos. 103 and 48A, the former of which had the platyrhine nose. In the aged skull, No. 105, the canine fossæ were deep. The orbital borders in No. 105 were thick, and the index of the aperture was microseme. The

* "Ueber die Indischen Parias," VON G. OPPERT, *Archiv für Anthropologie*, Bd. iv. Heft 2/3, p. 149, 1906.
† *Comparative Grammar of the Dravidian Languages*, p. 540, 2nd edition, London, 1875.
‡ *Phrenological Journal and Miscellany*, vol. v. p. 479, 1829.

Table II.*

Pariahs—Badaga.

	Pariahs.				Badaga.
	H.T.	H.T.	H.T.	E.U.A.M.	E.U.A.M.
Collection number,	103	104	105	48a.	
Age,	Aged.	Ad.	Aged.	Adoles.	Ad.
Sex,	M.	M.	M.	M.	M.
Cubic capacity,	1240	1162	1205	1223	1395
Glabello-occipital length,	177	179	172	174	181
Basi-bregmatic height,	130	135	128	131	131
Vertical Index,	*73·4*	*75·5*	*74·4*	*75·3*	*72·4*
Minimum frontal diameter,	88	91	96	93	96
Stephanic diameter,	97	107	113	111	116
Asterionic diameter,	101	96	92	99	106
Greatest parieto-squamous breadth,	126p.	123p.	129p.	128s.	140
Cephalic Index,	*71·2*	*68·7*	*75·*	*73·6*	*77·3*
Horizontal circumference,	498	488	488	484	520
Frontal longitudinal arc,	124	130	135	127	137
Parietal ,, ,,	132	124	112	122	128
Occipital ,, ,,	103	107	108	107	111
Total ,, ,,	359	361	355	356	376
Vertical transverse arc,	290	298	295	297	310
Basal transverse diameter,	115	108	114	114	119
Vertical transverse circumference,	405	406	409	411	429
Length of foramen magnum,	34	38	31	34	37
Basi-nasal length,	103	100	98	99	98
Basi-alveolar length,	99	...	97	96	97
Gnathic Index,	*96·1*	...	*99·*	*97·*	*99·*
Total longitudinal circumference,	496	499	484	489	511
Interzygomatic breadth,	126	...	123	120	127
Intermalar ,,	114	...	111	108	116
Nasio-mental length,	...	...	...	...	112
Nasio-mental complete facial Index,	...	...	...	...	*88·1*
Nasio-alveolar length,	60	...	63	60	63
Maxillo-facial Index,	*47·6*	...	*51·2*	*50·*	*49·6*
Nasal height,	42	...	45	47	47
Nasal width,	26	...	23	24	24
Nasal Index,	*61·9*	...	*51·1*	*51·1*	*51·1*
Orbital width,	37	...	37	36	36
Orbital height,	31	...	29	27	32
Orbital Index,	*83·8*	...	*78·4*	*75·*	*88·9*
Palato-maxillary length,	53	...	54	52	53
Palato-maxillary breadth,	56	...	64	64	61
Palato-maxillary Index,	*105·6*	...	*118·5*	*123·*	*115·*
Nasio-malar Index,	*111·7*	...	*111·8*	*110·7*	*105·3*
Lower jaw. Symphysial height,	...	...	...	...	31
Lower jaw. Coronoid ,,	...	...	...	...	64
Lower jaw. Condyloid ,,	...	...	...	...	65
Lower jaw. Gonio-symphysial length,	...	...	...	...	88
Lower jaw. Inter-gonial width,	...	...	...	...	102
Lower jaw. Breadth of ascending ramus,	...	...	...	...	30

* In this, as in the other Tables in this series of memoirs, E.U.A.M. signify Edinburgh University Anatomical Museum; and H.T., Henderson Trust.

palate in No. 103 was dolichuranic, but much wider in the other skulls. In two specimens the hard palate was deeply arched, and in the adolescent skull the maxillo-premaxillary suture was distinct. The teeth were for the most part lost: those present were stained with betel.

In No. 103 the sagittal and lambdoid sutures were ossified, in No. 105 all the sutures were closed, in the remaining two they were open and relatively simple. Two skulls had Wormian bones in the lambdoid. The parieto-squamous suture was well marked: no skull had an epipteric bone. No. 103 had an indication of a 3rd condyl and the lateral condyls were flattened. In the adolescent skull each external pterygoid plate was continuous with a process from the spine of the sphenoid, and the conjoint plate was pierced by two pterygo-spinous foramina.

A feature in this series of skulls was the small range of variation in most of their important dimensions, which pointed to a uniformity in type. The mean horizontal circumference was 489·5 mm., the mean vertical transverse 407·7, and the mean total longitudinal 492 mm. The mean length of the cranium was 175·5 mm., the mean height 131, and the mean breadth 126·5 mm.; the mean breadth-height index was hypsistenocephalic. The height exceeded the breadth in all except in No. 105, in which it was only 1 mm. less, and the mean vertical index was 74·6, metriocephalic. In one the cephalic index was 75, in the others below that figure, and the mean was 72·1, therefore distinctly dolichocephalic.

The mean facial indices were as follows: gnathic index, 97·3, orthognathous; maxillo-facial, 49·6, mesoprosopic; nasal, 54·7, due to the high platyrhine index of No. 103, but if that be excluded the mean nasal index, 51·1, was mesorhine; orbital, 79, all microseme; palato-maxillary, 115·7, faintly brachyuranic. The nasio-malar index ranged from 110·7 to 111·8, and the mean was 111·4, and the projection of the bridge of the nose beyond the plane of the malar borders of the orbits gave the face a somewhat pro-opic profile. The intracranial capacity was low for male skulls, and ranged from 1162 c.c. to 1240 c.c.: the mean was 1207·5 c.c.

Bishop Caldwell discussed the question whether the Pariahs were pre-Dravidian or belonged to the same race as the high-caste people of Southern India. Although several reasons of weight can be assigned in support of the theory of their pre-Dravidian origin, he inclined to the view that the lower castes in the Dravidian provinces are of the same race as the higher. He adduces in support of this position the essential unity of all the Dravidian dialects, and that there does not seem to be anything in the features of the Pariahs or in the colour of the skin which warrants the supposition that they are of a race different from their high-caste neighbours.

Mr Edgar Thurston published in 1896 and 1897 tables of comparative measurements of living natives of Madras,* to which reference may be made for details, but

* Madras Government Museum vol. i., *Bulletin* No. 4, p. 221, Madras, 1896; and vol. ii., *Bulletin* No. 1, Madras, 1897.

some mean measurements, which bear on the relation of the Pariahs to a higher caste, may usefully be reproduced :

	Stature.	Cephalic Index.	Nasal Index.
25 Tamil Bráhmans, . . .	162·5 cm. (64 in.)	76·5	76·7
25 Tamil Pariahs, . . .	161·9 „ (63¾ „)	73·6	80·

In mean stature the Tamil Pariahs were almost the same as the Tamil Bráhmans. The cephalic index was lower, for whilst 18 Pariahs were dolichocephalic, 6 approximated thereto and one was a little below 80, none was brachycephalic; whereas 7 Tamil Bráhmans were dolichocephalic, 12 approximated thereto, and 6 were brachycephalic or in the higher half of the mesaticephalic group. The mean nasal index in the Tamil Pariahs was higher than in the Bráhmans, and indicated a nose more platyrhine in its proportions.* Recently M. L. LAPICQUE has published † additional figures bearing on the stature and proportions of the head and nose of the Pariahs, as follows :

	Stature.	Cephalic Index.	Nasal Index.
23 Parias	163·7	76·1	78

These figures differ somewhat from those of Mr THURSTON. M. LAPICQUE discusses at some length the opinions expressed by Bishop CALDWELL, and arrives at a conclusion opposite to that of the distinguished Indian philologist.

When my measurements of the skulls of the Pariahs are compared with those of the dolichocephalic Tamil Sudras, it will be seen that though in both the mean index was dolichocephalic, the mean length was somewhat greater in the Pariahs; in both the mean height exceeded the breadth; the mean nasal index, No. 103 being excluded, was almost identical in the two series; the nasio-malar index in both showed a fair projection of the bridge of the nose, which was a little more pronounced in the Pariahs; in both the mean orbital index was low or microseme; the upper jaw in both was orthognathic, and the mean maxillo-facial index was mesoprosopic; in both the cranial capacity was low. The cranial and facial configuration of the Tamil Sudras and the Pariahs presented, therefore, important features of correspondence in their proportions, which are confirmatory of the opinion expressed by Bishop CALDWELL that there are strong racial affinities between both peoples.

BADAGA HILLMAN—NILGIRIS. TABLE II.

In July 1901 I received from Major D. SIMPSON, I.M.S., a package containing the skull and other bones of the skeleton of a Badaga Hillman of the Nilgiris, which Mr DASHE, Sanitary Inspector, had procured in response to a request made by Lieut.-Col. BANNERMAN, I.M.S. The man had died in the Coonoor Ghat, and, as the body had been buried, the bones were discoloured.

* In his interesting memoir, "The Coorgs and Yeruvas: an Ethnological Contrast" (*Journal Asiatic Soc.*, Bengal, vol. lxx. part iii. No. 2, 1901), Mr T. H. HOLLAND has compiled comparative tables of measurements of the Pariahs with other tribes and castes in Southern India.

† *Bull. et Mém. de la Soc. Anthrop. de Paris*, v^e^ série, t. vi. p. 400, 1905.

The skull was that of an adult male, and the teeth, with one exception, were complete, though the crowns were much worn and the dentine was exposed. In its external dimensions it was moderate in size, and the lower jaw was present.

Norma verticalis.—The cranium was broadly ovoid in outline, scarcely elevated in the sagittal region, the parietal eminences fairly prominent, and the slope downwards to them moderate, so that the cranium was "well filled." The side walls bulged slightly in the squamous region. The postero-parietal slope was gradual, the occipital squama bulged behind the inion, and there was no artificial flattening. The stephanic diameter much exceeded the asterionic. The parieto-squamous diameter was 13 mm. more than the interzygomatic, which again was 11 mm. more than the intermalar, and the skull was cryptozygous.

Norma lateralis.—The forehead sloped gently upwards, and the glabella and supraorbital ridges were moderate. The bridge of the nose was only 15 mm. long, concave upwards, somewhat rounded from side to side, and the nasion was depressed. The frontal longitudinal arc was the longest, and the occipital the shortest. The skull rested behind on the mastoid and on a process from the inion which projected downwards (Pl. IX., figs. 43–45).

Norma facialis.—The floor of the nose was not separated from the incisive region by a sharp ridge; the maxillo-nasal spine was feeble; the anterior nares were moderately wide and the nasal index was mesorhine, 51·1. The upper jaw projected somewhat forward and the index was 99, mesognathous. The face in both the complete and maxillo-facial indices was mesoprosopic. The canine fossæ were deeply hollowed. The orbital borders were not thickened, the apertures were low, and the index was mesoseme, 88·9. The palate was highly arched, the palato-maxillary region was moderately wide, and the index was brachyuranic, 115.

The cranial sutures were well denticulated and partially obliterated in the obelion. The pterion showed no irregular ossification, and there was no 3rd condyl or paracondylar process. The lower jaw was of moderate dimensions and the chin was well marked. The teeth were almost complete, flattened on the crowns with use, and stained with betel. The vertical index, 72·4, was metriocephalic, and the cephalic index, 77·3, was mesaticephalic; the parieto-squamous breadth was 9 mm. more than the basi-bregmatic height and the breadth-height index was platychamæcephalic. The intracranial capacity was 1395 c.c. The nasio-malar index, 105·3, was platyopic.

Pelvis.—The pelvis had male characters, and the muscular ridges were fairly well marked. The tubercle on the iliac crest was strong, the alæ were expanded and faintly translucent. The cotyloid cavity had a deep and wide notch in the margin. The pectineal ridges were moderate. The subpubic angle was 54°. The præ-auricular sulcus was scarcely recognisable. The back of the ilium, a part of the pubic body, the ischial tubera, and the back of the sacrum had been injured. The breadth-height index was moderate. The sides of the pelvic brim were smooth; the pelvic inlet was wide

and the brim index, 76·5, was markedly platypellic. The first coccygeal was fused with the last sacral vertebra. The sacrum had a moderately concave anterior surface; the base was 109 mm.; the length, not including the coccyx, was 93 mm.; the sacral index was 117, strongly platyhieric. The measurements are recorded below.

Measurements of Pelvis.

	mm.
Breadth of pelvis,	254
Height ,,	196
Breadth-Height Index,	*77·1*
Between ant. sup. iliac spines	220
,, outer borders ischial tubera,	118
Vertical diameter of obturator foramen,	47
Transverse ,, ,, ,,	32
Obturator Index,	*68*
Subpubic angle,	54°
Transverse diameter of pelvic brim,	115
Conjugate ,, ,,	88 app.
Pelvic or Brim Index,	*76·5*
Length of sacrum,	93
Breadth ,,	109
Sacral Index,	*117*

Spinal Column.—The vertebræ were not complete in number, and several were injured. *Cervicals*, the 5th, 6th, and 7th were missing; the spines of the 2nd, 3rd, and 4th were short and bifid. *Dorsals*, the 3rd was missing; the 10th, 11th, and 12th had each only a single costal facet on the side of the body; the 10th had no costal facet on the transverse process; in the 11th and 12th the transverse and spinous processes were broken off; the inferior costal facet on the side of the body from the 4th to the 8th dorsal was elevated on a process, and in the 9th the process was present though not marked by a facet. In the *Lumbar* vertebræ the spines and transverse processes were broken off, except in the 5th, in which they had the normal characters of that bone. Mammary and accessory processes were also present in the lumbars. Measurements of the lower dorsals and the lumbars are recorded below:—

	A.V.D.	P.V.D.	Index.	
9th Dorsal V.,	21 mm.	20 mm.	95·2	Special Index.
10th ,, ,,	21 ,,	21 ,,	100·	
11th ,, ,,	20 ,,	22 ,,	110·	
12th ,, ,,	21 ,,	25 ,,	119·	
	83 mm.	88 mm.	106·	General Index.
1st Lumbar V.,	23 mm.	26 mm.	113·	Special Index.
2nd ,, ,,	24 ,,	26 ,,	108·3	
3rd ,, ,,	24 ,,	23 ,,	95·8	
4th ,, ,,	24 ,,	22 ,,	91·6	
5th ,, ,,	25 ,,	21 ,,	84·	
	120 mm.	118 mm.	99·1	General Index.

The indices are obtained by the formula employed by Professor CUNNINGHAM and myself in our respective memoirs,* $\frac{\text{Post. Vert. Dr.} \times 100}{\text{Ant. Vert. Dr.}}$.

The special index is the relation of the two diameters in each vertebra; the general index is their relation in the group of vertebræ. As regards the four lower dorsal vertebræ, the vertical diameter of the bodies posteriorly collectively exceeded by 5 mm. the anterior vertical diameter, which without doubt partially contributed to the production of the forward concavity in the dorsal region. In the lumbar spine, on the other hand, the collective anterior vertical diameters of the bodies exceeded by only 2 mm. the vertical diameter posteriorly. The 1st and 2nd lumbars, like the lower dorsals, together had the posterior diameter 5 mm. longer than the anterior; the reverse was the case in the 3rd, 4th, and 5th lumbars, in which the collective diameters were 7 mm. more in front than behind. In the 3rd lumbar the vertical diameter anteriorly was only 1 mm. more than the posterior, and it may be regarded as marking the transition between the upper and lower wedge-shaped groups. No information could be obtained of the thickness of the intervertebral discs, or the part which they took in the production of the lumbar convexity of the spine; but as the general lumbar index was 99·1, as compared with a mean index of 96 in the spine of Europeans, the convexity in this region would have been due to the intervertebral discs rather than to a marked wedge-shaped character of the vertebral bodies. The lumbar spine in this skeleton comes into the group which, when regarded from the vertical diameters of the bodies and not including the discs, I have elsewhere named orthorachic,† or straight-spine.

Ribs.—Several ribs were missing, and of those present some were injured. No peculiarities were noticed.

Sternum.—This bone was injured, but neither the manubrium nor ensiform was ossified with the body.

The Upper Limb. Clavicles.—These bones were slender and with feeble muscular ridges. The sigmoid curve was not pronounced, and the groove for the subclavius muscle was scarcely marked. The right was 117 mm. long, the left 119 mm.

Scapula.—Both bones were so much injured that neither the full length nor breadth could be measured. The coracoid notch was deep, and the axillary border of the bone was almost straight.

Shaft of Upper Limb.—The humerus, radius, and ulna were slender bones, and with moderate muscular markings. The humerus had no intercondylar foramen; as the musculo-spiral groove was feeble, there was scarcely any twist in the shaft of the bone. The ulnar articular surface for the head of the radius was large, and indicated freedom of movement in pronation and supination; the axis of the neck of the radius was prolonged into that of the shaft; whilst the shaft of the radius curved away from that of

* CUNNINGHAM, *Nature*, February 18, 1886; and in CUNNINGHAM *Memoirs Royal Irish Academy*, 1886; TURNER, *Journal of Anatomy and Physiology*, April 1886; *Challenger Reports*, Zoology, part xlvii., 1886.

† Memoir in *Challenger Reports*, "On the Comparative Anatomy of the Human Skeleton," p. 72, part xlvii., 1886, *op. cit.*

the ulna, and the interosseous interval varied materially in transverse diameter, and at its widest was 20 mm. in the right forearm and 18 in the left.

	Right.	Left.
Humerus, extreme length,	313 mm.	310 mm.
Radius to tip of styloid,	254 „	253 „
„ base „	247 „	247 „
Ulna to tip „	273 „	...
„ lower articular surface,	270 „	270 „

The forearm was relatively long as compared with the upper arm, and the radio-humeral or ante-brachial index in the Badaga skeleton was 81, which places it in the group that I have elsewhere named dolichokerkic.

Shaft of the Lower Limb. Femur.—The bones were moderate in size. The extensor area of the head was distinctly prolonged on to the front and upper border of the neck. The anterior intertrochanteric line was moderately strong. The upper third of the shaft was somewhat flattened, and an external infratrochanteric ridge, distinct from the gluteal ridge and separated from it by a vertical groove, was present. The transverse diameter of the shaft a little below the small trochanter was 30 mm., and the antero-posterior was 22 mm.; the index of platymery was 73·3. The linea aspera was moderate; in the middle of the shaft the transverse diameter was R. 25, L. 24 mm., and the antero-posterior R. 24, L. 26 mm.; the pilastric index was R. 96 and L. 108. The popliteal surface was flattened. The condylar articular surfaces were well marked, and the internal condyl was prolonged obliquely upwards a little higher than the upper border of the intercondylar fossa.

Tibia.—The head of the right bone was slightly retroverted, that of the left a little more so. The internal condylar articular surface was concave, the external was concavo-convex. The muscular markings on the shaft were moderate. The antero-posterior diameter at the nutrient foramen was in the right 30 mm., in the left 31; whilst the transverse diameter was R. 24, L. 22 mm., the index in the right bone was 80, and in the left 70·9; the left bone was compressed laterally in the shaft

The lower end of the left tibia had an articular facet on the anterior border, but this was absent in the right bone. In both astragali the tibial articular surface was prolonged forward on the neck to 7 mm. from the upper edge of the scaphoid surface.

Fibula.—The muscular markings were distinct, though the bones were slender.

Patella.—Only the right bone was present, the diameters of which were 40 × 39 mm.

The bones of the shaft measured as follows:—

	Right.	Left.
Femur, maximum length,	442 mm.	439 mm.
„ oblique „	438 „	437 „
Tibia, from condyls to tip of malleolus,	365 „	374 „
„ „ astragalar surface,	355 „	365 „
Fibula, maximum length,	347 „	...

The proportion between the thigh and the leg was estimated by taking the oblique length of the femur and the condylo-astragalar length of the tibia as in the following formula $\frac{\text{tibial length} \times 100}{\text{femoral length}}$. Owing to the inequalities in the length of these bones in opposite limbs, the right tibia was to the femur as 81 to 100, and the left as 83·7, which figures are the tibio-femoral index. On the proportion shown by the longer of the two limbs it may be regarded as dolichoknemic. The relative lengths of the upper arm and thigh may be estimated from the maximum lengths of the humerus and femur in the formula $\frac{\text{humerus} \times 100}{\text{femur}}$. Computed by the method of M. Broca, the femoro-humeral index in this skeleton is 70; the humerus was shorter therefore in relation to the femur than in Europeans.

M. Broca has a formula for estimating the relative length of the upper and lower limbs, and obtaining an intermembral index from the maximum length of the bones: $\frac{\text{humerus} + \text{radius} \times 100}{\text{femur} + \text{tibia}}$. The index in this skeleton is 70, which points to a proportion between the shafts of the two limbs not unlike that found in Europeans.

The stature calculated from the length of the femur and tibia would probably have been about 5 feet $3\frac{1}{2}$ inches.

The Badagas are one of the five native tribes which occupy the Nilgiri Hills. Unlike the Todas, Kotas, Kurumbas, and Irulas, they are not regarded as an aboriginal race, but are supposed to have migrated from Mysore about three hundred years ago.* They are Hindus, are engaged in agriculture, and speak a language which closely resembles old Kanarese. They numbered in Madras and Coorg in 1901 (census) 34,229 people.

Mr Edgar Thurston has given a description of the physical characters based on the examination of forty living Badagas.† The mean stature was 164·1 c.m. (5 ft. $4\frac{1}{2}$ in.); the mean length of the head, 189 mm; breadth, 136 mm; cephalic index, 71·7, with a maximum 77·5 and a minimum 66·1; the nasal index ranged from 88·4 to 62·7, with the mean 75·6. In colour they were lighter than the other hill tribes, especially the women; they were smooth-skinned, of slender build, with narrow chest and shoulders. Mr Thurston does not appear to have had the opportunity of examining a Badaga skull. As I have only had a single specimen, my data are too few to formulate a general statement, but the cephalic index, 77·3, of the skull, was almost on a par with the maximum index, 77·5, of the living person obtained by Mr Thurston, and considerably higher than the mean, 71·7, of the index computed from his measurements. Thus, whilst the mean index was distinctly dolichocephalic, individuals had the cephalic index in the lower half of the mesaticephali, and the skull which I have measured came into the latter group.

* Ross King, *Journal of Anthropology*, No. 1, p. 18, July 1780. J. W. Breeks, *Primitive Tribes and Monuments of the Nilagiris*, London, 1873.

† *Bulletin Madras Government Museum*, vol. ii., No. 1, p. 7, 1897.

The nasal index in the skull was 51·1, whilst in the living people the average of the measurements was 75·6, a difference readily accounted for when it is kept in mind that the height of the nose is practically alike in the skull and the face, but that in the latter the alæ of the nose produce a width much greater than the width of the anterior nares. It has already been stated that the nasal index computed from the skull was mesorhine, and though in living persons the limits of the groups into which this index is arbitrarily divided are not numerically the same as in the skull, the mean obtained by Mr THURSTON is so distinct from the high platyrhine index of living negroes and Australians on the one hand, and the low leptorhine index of Europeans on the other, that it may fairly be regarded as mesorhine, though the range in measurement shows that some faces were distinctly platyrhine and others leptorhine.

THUGS. TABLE III.

In the early years of the nineteenth century the Government of India became aware of the existence of organised gangs of assassins, who frequented the great roads of communication, and, in the character of pilgrims, or men engaged in business, gained the confidence of other travellers, and committed wholesale murder and robbery. Their depredations were not confined to particular districts, but extended throughout India from north to south and east to west.* The name of Thugs was usually given to these assassins. An inquiry into their history showed that murder by strangling had been practised for a long period of time by certain families, who regarded the system of Thuggee as of divine origin, a rite authorised by the goddess Kalee or Bhawanee, and the persons murdered were looked upon by the Thugs as victims offered at the shrine of the goddess.

Although the practice of strangulation was pursued by families in whom it had become hereditary, and had assumed a caste-like distinction, children were occasionally adopted from other castes and trained to the occupation. There is a tradition that the early Thugs were Muhammadans, but in course of time Hindus became associated with them in the practice. About 1830 reports of the frequent murders of travellers caused the Governor-General, Lord WILLIAM BENTINCK, to take action for the suppression of this crime, and owing to the indefatigable zeal of Sir WILLIAM SLEEMAN, political officer at Saugor, Central Provinces, some hundreds of Thugs were captured, many of whom were hanged, and others transported and imprisoned. In course of time the organisation was crushed, and assassination by strangling as a profession has, it is believed, come to an end.

When, under the guidance of GEORGE COMBE, the phrenological doctrines and

* See memoir in *Asiatic Researches*, by R. C. SHERWOOD, in which they are called P'hansigárs, or Stranglers, vol. iii. p. 259 : Calcutta, 1820. In this memoir, as well as in a Report by Mr JOHN SHAKESPEAR, p. 282, the alternative names T'hegs and Badheks are given to them. See also *Ramaseena*, by W. H. SLEEMAN : Calcutta, 1836 ; *Edinburgh Review*, vol. lxiv. p. 357, 1837 ; *Quarterly Review*, vol. cxciv. p. 506, 1901.

methods of GALL and SPURZHEIM were keenly discussed and advocated in Edinburgh, a valuable collection of skulls from various parts of the globe was formed under the auspices of the Phrenological Society, and became the property of the Henderson Trustees. As the crania were collected for the purpose of studying the form of the head in association with the moral and intellectual character of the individual, much attention was paid to the acquisition of skulls of persons whose history and career were known.

In 1834 Mr HENRY HARPER SPRY, of the Bengal Medical Service, presented to the Phrenological Society seven skulls of Thugs, selected from a party of one hundred, who had been executed in 1832, at Saugor, Central Provinces.* Four of these skulls are in the Henderson Collection (Nos. 121–124), the other three (Nos. 125–127) are represented by casts. Two of the seven Thugs were Bráhmans, five were Musalmans. The Bráhmans, Dirgpaul (No. 121), and Gunga Bishun (No. 122), were convicted of numerous murders, and Dirgpaul, from his daring and success, was known by the Thugs as the Subahdar. The Musalmans, Soopher Sing (No. 123), Hosein Alee Khan (No. 124), Keramut Khan (No. 125), Buksha (No. 126), and Golab Khan (No. 127), were also well-known stranglers, and along with Dirgpaul the Bráhman, belonged to families who had been Thugs for generations. Mr ROBERT COX, a phrenologist, who reported on these skulls, stated that, with two exceptions, the organs of the propensities and lower sentiments preponderated over those of the higher faculties, but that in Hosein and Gunga there was no preponderance of either group, but that in them character had been determined by external circumstances.

Another series of four skulls (Nos. 128 to 131) are catalogued in the Henderson Trust Collection as Thugs, but without any details. Another, acquired from the Spurzheim Collection (Sp. c. 15), is that of Dhokul, a leading Thug, who was executed at Saugor in 1833. In the University Museum is the skull of a Thug hanged for murder, obtained from Colonel A. FRASER, Madras, and presented by Dr D. M. GREIG. I have also had the opportunity of examining the skull of a Thug from Northern India in the museum of the New College.

The series of Thugs comprised 11 skulls and 3 casts; they were all adult males, and two were aged. With the exception of two, the lower jaws were absent. In four specimens the cephalic index ranged from 75·4 to 77·8, two were below 70, and eight between 70 and 75. The general aspect of the series did not present any great range of variation, and they admit of being described as one group belonging to the dolichocephalic and lower term of mesaticephalic crania.

Norma verticalis.—In general form they were elongated and ovoid, though in one specimen the cephalic index was 77·8, which showed a proportionally wider transverse diameter; in some there was a tendency to a ridge-like elevation in the sagittal line, and in these a steep slope downwards to the parietal eminences existed, which gave a roof-like character to the cranium, but in others the transverse arc at the vertex was

* *The Phrenological Journal and Miscellany*, p. 511: Edinburgh, 1834.

more rounded. In the majority of the skulls the greatest width was in the squamous region. Seven crania were 180 mm. or upwards in length, and the shortest skull was 171 mm. There was no evidence of artificial flattening in the occipital region, the degree of the slope downwards from the obelion varied, but in three specimens (Nos. 121, 130, and F and G) it was abrupt, and in all the occipital squama projected behind the inion. No skull was asymmetrical. In two skulls the temporal curved lines were strong, which pointed to powerful temporal muscles. The crania were cryptozygous.

Norma lateralis.—As a rule the forehead scarcely receded, though in Nos. 121 and 130 (fig. 62) the backward slope was more pronounced; the glabella and supraorbital ridges were moderate, though stronger in a few specimens; the nasion usually was not much depressed. In all the skulls the occipital longitudinal arc was the shortest, in eight the parietal exceeded the frontal, in three the frontal was the longest. Some skulls rested behind on the mastoids, others on the cerebellar part of the occiput (Pl. X., fig. 54).

Norma facialis.—The floor of the nose was usually separated from the incisive region by a sharp ridge, though in a few, No. 129 especially, the ridge did not exist, and the nasal floor and the incisive fossæ were directly continuous: the maxillo-nasal spine was moderate. The bridge of the nose varied in length from 18 to 23 mm.; it differed also in the sharpness of the ridge, in its degree of projection, and in the depth of its upward concavity; but in no specimen was it flattened or specially wide, and the greatest interorbital diameter was 20 mm. The nasal height ranged in the skulls from 46 to 52 mm.; the nasio-alveolar length from 58 to 64 mm.; the width of the anterior nares ranged from 21 to 27 mm. The nasio-malar index ranged from 106·3 to 117·7, and the mean was 109·3. The upper jaw, though varying in the degree of projection, was prognathous in only one skull, No. 124, and orthognathous in four specimens. The orbital borders showed no special thickening, and the aperture had a wide range in the relation of width to height. The palato-maxillary arch was in several wide and shallow, though in a few the arch was higher; and in Nos. 121, 129 its vault opposite the 2nd molar was 16 mm. in height. In No. 130 the upper jaw was only 11 mm. in vertical diameter in the incisive region, and in No. 131 only 13 mm.

The sutures showed various degrees of complexity, and whilst open in some specimens, they were in others in process of ossification, and in two were almost obliterated. Small Wormian bones were in the lambdoid in six specimens; in another the occipital squama had as special ossifications a large mesial and a smaller right lateral supraoccipital; in another specimen a small triquetral occupied the posterior end of the sagittal suture. The parieto-squamous suture was, with two exceptions, well marked; in two skulls were epipteric bones, and in one of these, No. 123, the left squamous-temporal articulated directly with the frontal bone. In several the spine of the temporal was fused with the bone; in three the jugal processes were tuberculated; no skull had a 3rd condyl; in No. 123 each external pterygoid formed a continuous plate with the spine of the sphenoid, and the plate was pierced by a foramen. In No. 15 a broad-based exostosis projected into the auditory meatus from the anterior wall.

TABLE III.

Thugs.

			Henderson Trust. Skulls.									Casts.		
	E.A.U.M.	N.C.	SP.C.15.											
Collection number,	F. & G.	No. 7	...	128	129	130	131	121	122	123	124	125	126	127
Age,	Ad.	Ad.	Ad.	Ad.	Ad.	Ad.	Ad.	Aged.	Ad.	Ad.	Ad.	Aged.	Ad.	Ad.
Sex,	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.
Cubic capacity,	...	1235	1305	1285	1340	1218	1210	1360	1328	1275	1348	...	...	...
Glabello-occipital length,	184	171	180	182	176	175	173	187	181	176	176	185	176	186
Basi-bregmatic height,	133	130	134	125	135	130	132	133	135	128	123	...	...	...
Vertical Index,	*72·3*	*76·*	*74·4*	*68·7*	*76·7*	*74·3*	*76·3*	*71·1*	*74·6*	*72·7*	*69·9*	...	...	...
Minimum frontal diameter,	89	86	95	97	94	93	88	93	90	94	89	...	...	...
Stephanic diameter,	108	106	106	111	108	107	108	111	109	115	113	...	...	...
Asterionic diameter,	104	100	104	101	99	108	103	106	105	111	105	...	...	...
Greatest parieto-squamous breadth,	129p.	130s.	126p.	132s.	137s.	132s.	128s.	134p.	131p.	130s.	134s.	128	131	126
Cephalic Index,	*70·1*	*76·*	*70·*	*72·5*	*77·8*	*75·4*	*74·*	*71·7*	*72·4*	*73·9*	*76·1*	*69·2*	*74·4*	*67·7*
Horizontal circumference,	502	483	501	506	502	492	488	515	502	508	498	...	...	...
Frontal longitudinal arc,	125	122	123	130	122	119	122	132	123	123	133	...	...	...
Parietal ,, ,,	130	127	136	118	128	124	128	129	134	132	128	...	...	...
Occipital ,, ,,	111	112	111	113	110	108	110	122	119	107	109	...	...	...
Total ,, ,,	366	361	360	361	360	351	360	383	376	362	370	...	...	...
Vertical transverse arc,	303	293	298	288	306	300	297	302	300	293	309	...	...	...
Basal transverse diameter,	114	114	110	122	121	122	121	113	114	113	115	...	...	...
Vertical transverse circumference,	417	407	408	410	427	422	418	415	414	406	424	...	...	...
Length of foramen magnum,	29	30	38	32	34	30	34	34	38	36	...	...	...	...
Basi-nasal length,	109	94	103	99	105	105	96	96	99	91	97	...	...	...
Basi-alveolar length,	111	89	102	98	103	97	96ap.	92	95	92	102	...	...	...
Gnathic Index,	*101·8*	*94·7*	*99·*	*99·*	*98·1*	*92·4*	*100·*	*95·8*	*96·*	*101·1*	*105·2*	...	...	...
Total longitudinal circumference,	504	485	501	492	499	486	491	513	513	489	...	...	...	...
Interzygomatic breadth,	122	123	127	134	132	131	129	125	123	126	123	...	...	...
Intermalar ,,	106	113	117	119	121	118	113	114	110	115	111	...	...	...
Nasio-mental length,	104	106	...	...	...	...	...	...	...	...	...	...	...	...
Nasio-mental complete facial Index,	*85·2*	*86·1*	...	...	...	...	...	...	...	...	...	...	...	...
Nasio-alveolar length,	65	64	60	66	70	58	63	74	64	67	62	...	...	...
Maxillo-facial Index,	*53·2*	*52·*	*47·2*	*49·2*	*53·*	*44·2*	*48·8*	*59·2*	*52·*	*53·1*	*50·4*	...	...	...
Nasal height,	50	46	46	48	52	48	50	52	50	50	49	53	54	51
Nasal width,	25	22	24	24	25	26	25	24	25	21	27	27	26	27
Nasal Index,	*50·*	*47·8*	*52·2*	*50·*	*48·2*	*54·2*	*50·*	*46·*	*50·*	*42·*	*55·1*	*50·9*	*48·1*	*52·9*
Orbital width,	40	35	38	38	37	38	36	39	37	37	36	...	...	...
Orbital height,	31	30	31	33	32	30	33	33	34	33	31	...	...	...
Orbital Index,	*77·5*	*85·7*	*81·6*	*86·8*	*86·5*	*78·9*	*91·7*	*84·6*	*91·9*	*89·2*	*86·1*	...	...	...
Palato-maxillary length,	61	52	54	...	60	55	54	51	55	51	58	...	...	...
Palato-maxillary breadth,	64	61	64	67	62	59	63	62	64	63	62	...	...	...
Palato-maxillary Index,	*105·*	*117·3*	*118·5*	...	*103·3*	*107·2*	*116·9*	*121·5*	*116·3*	*123·5*	*107·*	...	...	...
Nasio-malar Index,	*117·7*	*106·6*	*107·9*	*111·2*	*107·2*	*110·3*	*106·3*	*109·4*	*108·5*	*107·3*	*110·6*	...	...	...
Lower jaw. Symphysial height,	31	30	...	...	...	...	...	...	...	...	...	...	...	...
Lower jaw. Coronoid ,,	56	62	...	...	...	...	...	...	...	...	...	...	...	...
Lower jaw. Condyloid ,,	65	57	..	...	...	...	...	...	...	...	...	...	...	...
Lower jaw. Gonio-symphysial length,	81	82	...	...	...	...	...	...	...	...	...	...	...	...
Lower jaw. Inter-gonial width,	80	90	...	...	...	...	...	...	...	...	...	...	...	...
Lower jaw. Breadth of ascending ramus,	31	31	...	...	...	...	...	...	...	...	...	...	...	...

An analysis of the measurements recorded in Table III. gives the following results. The maximum length of fourteen specimens ranged from 171 to 187 mm., and the mean was 179 mm. The greatest breadth ranged from 126 to 137 mm., and the mean was 130·6 mm. The mean cephalic index was 72·9. It is to be noted that in seven specimens the absolute length exceeded 180 mm., and in these the highest cephalic index was 72·5 and the lowest 67·7 : the dolichocephalic proportion was therefore strongly marked. In the remaining seven the length varied from 171 to 176 mm., and the cephalic index ranged from 73·9 to 77·8 and the mean was 75·3, a fraction higher than the highest numerical term of the dolichocephali.

In eleven in which the height was taken it ranged from 123 to 135 mm., and the mean was 130·7 mm. The mean vertical index was 73·3, *i.e.* metriocephalic. It should be noted that in only four skulls did the height exceed the breadth, and in these the highest cephalic index was 74 ; but in three other skulls, with cephalic indices 71·7, 72·5, 73·9 respectively, and therefore dolichocephalic, the breadth exceeded the height. In some skulls therefore the breadth-height index was platychamæcephalic, in others hypsistenocephalic.

As regards the proportions of the face, the upper jaw varied in the degree of projection : four skulls were orthognathous, six mesognathous, one prognathous, and the mean of the series was 98·4, mesognathous or a moderate projection. In only two could the complete facial index be computed, and the proportion of length to breadth was mesoprosopic. The maxillo-facial index was computed in all the skulls : one was chamæprosopic, three mesoprosopic, seven leptoprosopic, and the mean of the series, 51·1, was leptoprosopic, *i.e.* a relatively long and narrow face. The nasal index showed considerable variation : three were leptorhine, two platyrhine, nine mesorhine, and the mean, 49·8, was mesorhine. No skull was platyopic in the profile of the nose, which as a rule had a fair extent of projection. In three skulls the orbital aperture was rounded and with megaseme index, in three it was low and microseme, in the remainder mesoseme, and the mean of the series, 85·5, was mesoseme. In the palato-maxillary arch four were dolichuranic, four brachyuranic, and two hyperbrachyuranic, and the mean, 113·6, was mesuranic : the form of the arch generally was moderately wide.

The mean intracranial capacity of ten skulls was 1290 c.c. ; they ranged from 1210 to 1360 c.c. ; the highest was considerably below the mean capacity of male European crania.

This analysis of the series of fourteen specimens of Thugs shows that no cranium was brachycephalic, in only four the cephalic index was above 75, and the highest of these was 77·8. Ten were dolichocephalic, and of these two were hyperdolichocephalic, and the nasio-malar index was not platyopic. It is obvious therefore that the professional stranglers were not drawn from the brachycephalic Mongoloid tribes which occupy the districts along the Himalayan frontier. As a narrow leptorhine nose was found in only a small proportion of these skulls, and as the nasal index was for the most part either mesorhine or platyrhine, it would seem as if these people had Dravidian

affinities. This conclusion is supported by the length and marked dolichocephalic proportion of the cranium, which is more pronounced in the Dravidian tribes than in Indo-Aryans like the high-caste Bráhmans of Bengal.*

It should, however, be pointed out that the relatively long and narrow (leptoprosopic) face possessed by the greater number of the skulls is an Indo-Aryan character, so that possibly these families of Thugs were the result of intermarriage between members of the two dominant Dravidian and Indo-Aryan races.† Their religion, Hindu or Musalman as the case might be, would have been determined by the traditions and usage of their families, and by the prevailing religion of the district in which they lived.

Much has been written of late years on the skulls of those who had committed serious crimes, and a criminal type of skull has been looked for. As the Thugs had reduced assassination and robbery to a system, and carried it on in a wholesale manner, so that when a party of travellers was attacked no one was allowed to escape, and the dead bodies were buried without leaving a trace, and as these practices had been hereditary in families throughout several generations, the conditions, it may be thought, were such as to favour the production of a type of head indicative of moral perversion. The skulls were therefore examined for stigmata or characters which could be associated with a low development, or with degenerative changes in the head.

The lower region of the forehead, as a rule, ascended almost vertically from the glabella and supraorbital ridges, which were not specially prominent, and the nasion was not depressed. The vertex was not flattened, the cranial vault was arched (figs. 54, 63), and the mean height was about equal to the mean breadth. In two specimens, however, the forehead was retreating, and the glabella and supraorbital ridges were prominent (fig. 62). Although in several skulls the cranial sutures were undergoing obliteration from age, there was no sign of premature synostosis; and the presence of sutural bones, and modifications in ossification in the pterion, were not more frequent than is often met with in a similar number of skulls not obtained from criminals. The crania were not deformed either from artificial pressure or from developmental irregularity, and there was no departure from the customary symmetry. The dentition was normal, and in only one upper jaw were the wisdom teeth not erupted. The hard palate was usually shallow and moderately wide, but in two specimens it was highly arched and its depth was 16 mm. opposite the second molars. The maxillo-premaxillary suture was faintly marked in a few of the palates. In one skull the atlas was ossified to the occipital bone, but no specimen had a third condyl. Although the intracranial

* Mr Risley, in his *Anthropometric Data of the Tribes and Castes of Bengal*, vol. i. p. 21, e.s. Calcutta, 1891, gives a table of measurements of a hundred Bráhmans. In 32 the cephalic index was 80 and upwards, in 30 it was from 77·5 to 79·9, in 25 from 75 to 77·4, and in only 13 it was below 75. When an allowance is made for the difference between the index in the living head and in the skull, there still remains a decided preponderance in the Bráhmans of heads either brachycephalic or approximating thereto.

† The influence exercised by intermarriage on the physical characters of a race is discussed in Mr T. H. Holland's interesting study in Contact Metamorphism, which shows the nature and degree of physical modification of the Kulu Kanet caste, owing to true blood fusion with the Mongoloid Kanets of Lahoul in the Western Himalayas (*Journ. Anth. Inst.*, vol. xxxii. p. 96, 1902).

capacity was much less than in male Europeans, it was higher than that of the Tamil Sudras and the Pariahs. This group of Thug skulls possessed in common no series of characters which one could associate with such maldevelopments or degenerations as have, by some authors, been regarded as giving evidence of a criminal type.

VEDDAHS. Table IV.

Since I described in Part II. of these Contributions to Indian Craniology nine Veddah crania, not previously recorded, the Anatomical Museum of the University has received three skulls, one of which was accompanied by a large part of the skeleton. They were adults, and apparently males. One, C in Table IV., was presented in 1902 by F. V. Harper, Esq., of Vogan, in recognition of the services rendered to the Museum by the late Mr James Simpson, Assistant Curator; another, D, with the skeleton, was presented in August 1905 by H. O. Hoseason, Esq., of Denodera, Ceylon; and a third, E, in November of the same year by Dr Lorenz Prins of Ceylon.

The skulls resembled each other in general form, size, and the proportions of the cranium. They were dolichocephalic.

Norma verticalis.—The crania were neither flattened nor ridged in the sagittal region; the parietal eminences in C were strong, and the cranium had a pentagonal outline; in the other two the outline was an elongated ovoid. The vault sloped distinctly downwards and outwards from the sagittal line to the parietal eminences. In one the side walls were vertical below the parietal eminences, in the others they were slightly bulging. The post-parietal region sloped downwards and backwards, the occipital squama bulged behind the inion, and D showed slight want of symmetry behind. In two skulls the parieto-squamous diameter was only 3 mm. more than the inter-zygomatic, in one it was 4 mm. less. Two crania were phænozygous, one was cryptozygous.

Norma lateralis.—The forehead was almost vertical. The glabella and supraorbital ridges were feeble. The nasion was depressed in two crania, but not in the third. The bridge of the nose in C was only 16 mm. long, rounded from side to side, concave upwards and forwards. The anterior nares were wide in relation to the height of the nose, and the nasal index was platyrhine. In D and E the nasal bridge was 21 mm. long and not so rounded or so concave; the nasal height was relatively much greater than the width, and the nasal index was leptorhine. In all three crania the occipital longitudinal arc was the shortest, and the parietal arc was considerably longer than the frontal. The crania in two specimens rested behind on the cerebellar fossæ; in one on the occipital condyles.

Norma facialis.—The orbital borders in C were thick, but sharp in the others. In C an infraorbital suture was visible, and the canine fossæ were deep. In D and E the floor of the nose was separated from the incisive region by a sharp ridge. In E the incisive region was only 5 mm. in vertical diameter, and the face was consequently

Table IV.

Veddahs.

		C.	D.	E.
Collection number,		Vogan.	Denodera.	Prins.
Age,		Ad.	Ad.	Ad.
Sex,		M.	M.	M.
Cubic capacity,		1350	1375	1225
Glabello-occipital length,		178	172	170
Basi-bregmatic height,		134	131	135
Vertical Index,		*75·3*	*76·2*	*79·4*
Minimum frontal diameter,		87	90	93
Stephanic diameter,		101	109	105
Asterionic diameter,		99	113	97
Greatest parieto-squamous breadth,		129p.	129s.	127s.
Cephalic Index,		*72·5*	*75·0*	*74·7*
Horizontal circumference,		499	495	485
Frontal longitudinal arc,		132	126	125
Parietal ,, ,,		138	131	138
Occipital ,, ,,		105	100	96
Total ,, ,,		375	357	359
Vertical transverse arc,		290	300	298
Basal transverse diameter,		114	118	108
Vertical transverse circumference,		404	418	406
Length of foramen magnum,		34	36	31
Basi-nasal length,		95	97	99
Basi-alveolar length,		94	92	91
Gnathic Index,		*98·9*	*94·8*	*91·9*
Total longitudinal circumference,		504	490	489
Interzygomatic breadth,		126	133	124
Intermalar ,,		112	119	112
Nasio-mental length,		97	119	...
Nasio-mental complete facial Index,		*77·*	*89·4*	...
Nasio-alveolar length,		54	67	55
Maxillo-facial Index,		*42·8*	*50·3*	*44·3*
Nasal height,		43	50	50
Nasal width,		24	22	24
Nasal Index,		*55·8*	*44·*	*48·*
Orbital width,		35	39	38
Orbital height,		31	36	31
Orbital Index,		*88·6*	*92·3*	*81·6*
Palato-maxillary length,		51	52	48
Palato-maxillary breadth,		60	60	56
Palato-maxillary Index,		*117·6*	*115·4*	*116·6*
Nasio-malar Index,		*108·3*	*109·2*	*110·3*
Lower jaw.	Symphysial height,	28	31	...
	Coronoid ,,	56	61	...
	Condyloid ,,	58	62	...
	Gonio-symphysial length,	82	87	...
	Inter-gonial width,	95	98	...
	Breadth of ascending ramus,	32	34	...

chamæprosopic. In the platyrhine skull, C, the floor of the nose was continued by a smooth surface into the incisive region, and the maxillo-nasal spine was feeble, the upper jaw was mesognathic, the face was low both in the complete and maxillo-facial regions, and the orbital apertures were also low. In D and E the jaw was orthognathic. In D the face was relatively long and the orbit was rounded; in E the orbits were low. In all three the palato-maxillary region was moderately wide.

The cranial sutures were not obliterated, and as a rule were simple. D and E had small Wormian bones in the lambdoid, and D had a large right epipteric. No 3rd condyl or paracondylar process was present, but E had a pair of small pointed processes projecting downwards immediately in front of the basion. The teeth were stained with betel and partially worn. The lower jaws were moderate in dimensions and with good chins.

The mean external dimensions were as follows: length, 173·3 mm.; height, 133·3; breadth, 128·3; horizontal circumference, 493; vertical transverse circumference, 409·3; total longitudinal circumference, 494·3 mm. In each skull the height was more than the breadth; the mean vertical index was 76·9, hypsicephalic; the mean cephalic index was 74, dolichocephalic; the breadth-height index was hypsistenocephalic. The mean facial indices were as follows: gnathic, 95·2, orthognathic; complete facial in two skulls with lower jaws, 83·2, chamæprosopic; maxillo-facial in three skulls, 45·8, mesoprosopic; nasal, 49·2, mesorhine; orbital, 87·5, mesoseme; palato-maxillary, 116·3, brachyuranic. The mean nasio-malar index was 109·2. The intracranial capacity ranged from 1225 c.c. to 1375, and the mean was 1316 c.c.

The skull D, from Denodera, was accompanied by many of the other bones of the skeleton, and, with the exception of the sternum, a few vertebræ and ribs, and some of the small bones of the hands and feet, the skeleton was in good order and complete.

Pelvis.—The pelvis had definite male characters, though in external dimensions it was small for an adult and considerably below the European standard. The breadth, 231 mm., exceeded the height, 189 mm., and the breadth-height index was 81·8. The subpubic angle was 68°. The tubercle of the iliac crest was moderate, the alæ were somewhat expanded, and the iliac fossæ scarcely transmitted any light. The pectineal lines and pubic spines were low; the muscular ridges were feeble. Each præ-auricular sulcus was a shallow, vertical groove. The transverse diameter of the pelvic brim exceeded the conjugate, and the pelvic index was 94·6, *i.e.* in the mesatipellic group. The obturator foramen had a relatively high index, 72·2. The anterior surface of the sacrum had a shallow concavity; the upper three vertebræ had sacral spines, but in the 4th and 5th the laminæ had not united mesially, and terminated in blunt processes which represented bifid spines. The 1st coccygeal vertebra was fused with the last sacral, but was not included in the measurement of sacral length. The breadth of the base of the sacrum slightly exceeded the length of the bone, and the index, 102, placed the bone in the lower term of the platyhieric group.

The chief measurements are stated below.

Measurements of Pelvis.

	mm.
Breadth of pelvis,	231
Height ,,	189
Breadth-Height Index,	*81·8*
Between ant. sup. iliac spines,	208
,, post. ,, ,,	75
,, outer borders of ischial tubera,	123
Vertical diameter of obturator foramen,	43
Transverse ,, ,, ,,	31
Obturator Index,	*72·2*
Subpubic angle,	68°
Between inner borders of ischial tubera,	91
Transverse diameter of pelvic brim,	111
Conjugate ,, ,,	105
Pelvic or Brim Index,	*94·6*
Length of sacrum,	98
Breadth ,,	100
Sacral Index,	*102*

Spinal Column.—The *cervical* vertebræ were small; the axis and the 4th cervical vertebræ were missing; the spines of the 3rd, 6th, and 7th were not bifid, that of the 6th was not so prominent as that of the 7th. The foramen at the root of the transverse process was relatively large, but a bar of bone divided the left foramen of the 6th into two parts. In the *dorsal* region the 9th, 10th, 11th, and 12th vertebræ had each only a single costal facet on the side of the body. The 10th had no costal articular surface on each transverse process, which in the 11th and 12th was represented by three tubercles. In the 5th, 6th, 7th, and 8th dorsal vertebræ the inferior costal facet on the side of the body was elevated as a costal process, but the superior facet was in the plane of the general surface of the body. In the *lumbar* region the vertebræ had blunt, stunted mammillary processes, and in three short, pointed, accessory processes were also present. In the 1st, 2nd, and 3rd the transverse processes were spatulate, in the 4th they were attenuated, and in the 5th thick and stunted. The spines were characteristic of the region.

The bodies of the four lower dorsals and those of the lumbar vertebræ were measured to determine the vertical diameter in front and behind, and the measures are recorded below:—

	A.V.D.	P.V.D.	Index.	
9th Dorsal V.,	19 mm.	19 mm.	100·	
10th ,, ,,	19 ,,	20 ,,	105·2	Special Index.
11th ,, ,,	18 ,,	22 ,,	122·2	
12th ,, ,,	21 ,,	24 ,,	114·3	
	77 mm.	85 mm.	110·4	General Index.

	A.V.D.	P.V.D.	Index.	
1st Lumbar V.,	25 mm.	26 mm.	104·	
2nd ,, ,,	27 ,,	27 ,,	100·	
3rd ,, ,,	26 ,,	27 ,,	103·8	Special Index.
4th ,, ,,	25 ,,	26 ,,	104·	
5th ,, ,,	25 ,,	23 ,,	92·	
	128 mm.	129 mm.	100·7	General Index.

In this spine the collective posterior vertical diameter of the bodies of the four lower dorsals was 8 mm. more than the anterior. In the lumbar vertebræ the collective posterior diameter was 1 mm. more than the anterior, instead of, as is customary in Europeans being several mm. less, and the general lumbar index was 100·7. The last lumbar was the only vertebra in which the anterior diameter of the body exceeded the posterior. The almost equality in the two diameters was such as to reduce the wedge-shaped form of the bodies to a minimum, and the spine, so far as its curvature was dependent on their shape and not on that of the intervertebral discs, was a straight spine, orthorachic.

Ribs.—These bones were not complete. Those present indicated a thorax of moderate dimensions and showed no special variations from the normal.

Bones of the Upper Limb.—The *Clavicles* were slender and with well-marked sigmoid curves; the muscular ridges were feeble, and the groove for the subclavius muscle was shallow. The articular surfaces were smooth and not extensive. The right bone was 140 mm. long, the left 148 mm.

The *Scapulæ* were also slender, and with the muscular markings relatively feeble; the axillary border was almost straight, the vertebral border was sharp, and the inferior angle was rounded; the spine and acromion were normal; the right coracoid notch was deep and wide. The right bone was 143 mm. in length and 101 in breadth; the left bone was 144 mm. long and 102 broad; the right scapular index was 70·6, the left was 70·8. The right infraspinous length was 103 mm., and the infraspinous index was 98; the left infraspinous length was 102 mm. and the index was 100.

Shaft of Upper Limb.—The humerus, radius, and ulna were slender, and with the muscular ridges moderate. In the humerus the musculo-spiral groove was shallow and the shaft showed scarcely any twist; in the right bone was a minute, intercondylar foramen, but neither bone had a supracondylar process. The ulnar articular surface for the head of the radius was large, and indicated free range of movement between the bones. The axis of the neck of the radius was set at an angle to that of the shaft. The axis of the shaft of the ulna was almost vertical. The interosseous interval between the bones was 17 mm. in its widest transverse diameter. The length of the bones was as follows:—

	Right.	Left.
Humerus, from head to tip of trochlea,	339 mm.	331 mm.
Radius ,, ,, ,, styloid,	257 ,,	257 ,,
,, ,, ,, base ,,	250 ,,	252 ,,
Ulna from olecranon to tip of styloid,	278 ,,	276 ,,
,, ,, ,, lower articular surface,	274 ,,	272 ,,
Radio-humeral (antebrachial) index,	75·8	77·6

The forearm was moderately long in proportion to the upper arm, and the resulting index is mesatikerkic.

Shaft of the Lower Limb.—The *Femur* was a well-shaped bone with the muscular processes and ridges moderately developed. The articular surface of the head had the extensor area faintly prolonged for a short distance outwards on the front and upper border of the neck. The anterior intertrochanteric line was thick and roughened and indicated a strong anterior ilio-femoral ligament and power of complete extension of the hip-joint. No flattening of the upper third of the shaft of the femur existed, and there was no external infratrochanteric ridge distinct from the gluteal ridge. The transverse diameter of the shaft a little below the small trochanter was 28 mm., and the antero-posterior diameter in the same plane was 23 mm.; the platymeric index was 82. At the middle of the shaft the transverse diameter was 25 mm. and the antero-posterior was 27 mm., which gave a pilastric index 108. The popliteal surface of the shaft was faintly concave. Each internal condyle had the articular surface behind prolonged a little above the upper border of the intercondylar fossa.

Tibia.—The head showed considerable retroversion; the internal condylar surface was concave and the external was concavo-convex. The vertical axis of the shaft formed with that of the head a distinct angle. The shaft was laterally compressed and with a sharp anterior border. In the right bone the antero-posterior diameter in the plane of the nutrient foramen was 31 mm., and the transverse diameter was 19 mm.; the shaft therefore was platyknemic, with an index 61·3. The corresponding diameters in the left bone were 32 and 19 mm., and the index of platyknemia was 59·3. The astragalar articular surface was slightly prolonged on the anterior border of the lower end of the bone. The supero-external part of the tibial surface of the astragalus was slightly prolonged on the neck of that bone, but did not nearly reach the scaphoid articular surface.

Fibula.—This bone was slender and with feeble muscular markings.

	Right.	Left.
Femur, maximum length, ...	435 mm.	435 mm.
„ oblique length, ...	432 „	430 „
Tibia from condylar surfaces to tip of malleolus, . .	370 „	369 „
„ „ „ astragalar surface, . .	356 „	358 „
Fibula, maximum length, ...	361 „	362 „

The inequalities in the length of the bones in opposite limbs were so slight that it will suffice to state the limb indices on the right side only. The tibio-femoral index was 82·4, so that the leg was relatively long and almost in the dolichoknemic group. The femoro-humeral index was high, 78, and the humerus was therefore relatively long. The intermembral index, 74, was also high in the Veddah skeleton.

As the descriptions by Busk, Flower, De Quatrefages and Hamy, Barnard Davis, Rolleston, Virchow, Arthur Thomson, and Paul and Fritz Sarasin on the skulls of Veddahs have been considered in Part II. of these memoirs, it is not necessary again

to comment on them. It may suffice therefore to limit myself to a comparison of those previously recorded with this additional series. The crania in the present set were, as in those previously described, elongated, not keeled in the sagittal region, dolichocephalic, the height greater than the breadth. The face was low in relation to its height; the nose was usually platyrhine or mesorhine; the upper jaw was usually orthognathous; the orbital aperture trended to a high vertical diameter; the palato-alveolar arch was moderately wide. The mean cranial capacity in this series, 1316 c.c., was higher than in the men measured in Part II., 1201 c.c., and also higher than the mean, 1250, given in the memoir of the Messrs SARASIN.

As in the present series I have examined an almost complete skeleton, and as this opportunity seldom occurs, it will be of interest to compare it with specimens recorded in 1889 by Professor ARTHUR THOMSON,* and with the more numerous examples subsequently described by the Messrs SARASIN in their monumental work on Ceylon.†

The bones were well formed, slender, and not strongly marked with ridges and processes for muscles. The height and breadth of the pelvis closely corresponded in THOMSON's and my specimens, and the breadth-height index, as well as in the males described by the SARASINS, ranged from 80·9 to 81·8. The index of the pelvic brim showed considerable variation. In eight men measured by the SARASINS the mean index was 89·9, in my specimen 94·6, and in these the transverse diameter exceeded the conjugate; but in THOMSON's specimen the conjugate was 3 mm. more than the transverse, and the index, 103, was dolichopellic.

In all the male skeletons it was seen that the collective depth posteriorly of the bodies of the lumbar vertebræ exceeded somewhat the depth anteriorly, and the lumbar curve, so far as it was occasioned by the bones, was concave anteriorly or koilorachic. In these skeletons the length of the forearm in relation to the upper arm was intermediate between Europeans and Negritos, and falls into the group which I have named mesatikerkic. The tibia was also long in relation to the femur, and the tibio-femoral index was dolichoknemic. In my specimen the intermembral index, 74, was much higher than in THOMSON's, 66·1, and in the SARASINS' specimens, 68·9, and must be regarded therefore as exceptional. In my skeleton and in those measured by the SARASINS the index of the tibial shaft was strongly platyknemic, but the mean of six tibiæ measured by THOMSON gave an index 74·5, which showed that there was only slight lateral compression of the shaft. From the measurements of the Messrs SARASIN the mean stature of the Veddah men was 5 feet 2 inches, of the women 4 feet 10 inches.

TIBETANS. TABLE V.

In February 1905 I had the pleasure to receive from a former pupil, Major C. N. C. WIMBERLEY, I.M.S., two crania which he had collected when in Tibet as a member of the medical staff attached to the expedition to Lhasa under the command of Sir FRANK

* *Jour. of Anthr. Inst.*, Nov. 1889. † *Ergebnisse naturwissenschaftliche Forschungen auf Ceylon*; Wiesbaden, 1893.

E. Younghusband, K.C.I.E. One without the lower jaw was labelled as the skull of a typical inhabitant of Lhasa; the other, with the lower jaw attached, judging from the clothing and hair, was regarded as that of a Kham warrior from Eastern Tibet. They were picked up on the sites where engagements had been fought between the Tibetan forces and the British troops during the recent campaign.

Lhasa. Table V.

The skull from Lhasa was that of an adult male. The cephalic index was 79·3, and the cranium, though not numerically brachycephalic, so closely approximated thereto in form and proportion, that it should be referred to that group.

Norma verticalis.—The outline was broadly ovoid, and the frontal longitudinal arc was 4 mm. longer than the parietal, the vertex was not flattened, and the cranium had a well-marked slope from the sagittal line to the parietal eminences. The side walls were slightly bulging; the parieto-occipital slope was steep, though not abrupt; the occipital squama was not flattened and projected slightly behind the inion. The parieto-squamous breadth was 7 mm. more than the interzygomatic. The skull was cryptozygous.

Norma lateralis.—The forehead was wide and flattened from side to side, it had only a slight backward slope, and the frontal eminences were moderate. The glabella and supraorbital ridges were not prominent. The nasion was not depressed. The bridge of the nose was low, flattened, and it projected so little at the tip that the concavity upwards was very shallow. The nasal bones were 26 mm. long. The interorbital width was 24 mm. The frontal longitudinal arc was 22 mm. longer than the occipital arc. The cranium rested behind on the cerebellar fossæ of the occiput (Pl. IX., figs. 46–48).

Norma facialis.—The floor of the nose was separated by a low, smooth border from the incisive region of the maxilla. The maxillo-nasal spine was feeble. The anterior nares were broad and indicated wide nostrils during life, but as the height of the nose was long in proportion, the nasal index worked out as mesorhine. The upper jaw projected a little and the index was mesognathous, 100. The maxillo-facial index, 55·5, was leptoprosopic, owing to the length of the superior maxilla. The canine fossæ were deep. The wide interzygomatic and intermalar diameters, the low, flattened, nasal bridge, the upper orbital border almost transverse, the malar border being in a plane only slightly posterior to the bridge of the nose, the nasio-malar index 105·1 and the markedly platyopic face were characteristic. The upper and outer borders of the orbit were not thick: the orbital aperture was rounded and megaseme. The palato-maxillary region was moderately wide and the index was brachyuranic. The teeth were fully erupted, not much worn, and not stained with betel.

The sagittal suture was partially obliterated at the obelion. The other sutures were distinct, the parieto-squamous had an epipteric bone. No 3rd condyl or paracondylar

process was present. The mastoids and inion were well marked. The vertical index, 73·7, was metriocephalic; as is customary in brachycephali, the height was not equal to the breadth, the cephalic index was 79·3, and the breadth-height index was platychamæcephalic. The intracranial capacity was 1520 c.c., on a par with the mean capacity in Europeans.

Kham Province. Table V.

The province of Kham forms the eastern part of Tibet, and lies north-east of the Brahmaputra before that river makes the great bend to the south and west. The skull of the Kham warrior was dolichocephalic, with the length-breadth index 74·5. It was a powerful adult male, and had a lower jaw.

Norma verticalis.—The cranium was elongated and ovoid in outline, with the parietal longitudinal arc 11 mm. longer than the frontal: the sagittal line was somewhat elevated, the parietal eminences were distinct, and the vault sloped steeply from the sagittal suture to these eminences, below which the side walls were vertical. The highest point of the temporal ridge was 32 mm. from the sagittal suture. The parieto-occipital slope was more gentle than in the skull from Lhasa, and the occipital squama bulged behind the inion. The stephanic diameter was 26 mm. less than the inter-zygomatic, and the skull was phænozygous.

Norma lateralis.—The forehead was receding, the frontal eminences were scarcely recognisable, and the frontal bone from the middle line to each temporal ridge sloped backwards. The glabella and supraorbital ridges were prominent, and the internal orbital process was thick: the nasion was a little depressed. The bridge of the nose, though not projecting, was not so wide and flattened as in the Lhasa skull, and was somewhat concave: the nasal bones were 27 mm. long, the interorbital width was 21 mm. The parietal longitudinal arc was 29 mm. longer than the occipital. The cranium rested behind on the cerebellar fossæ (Pl. X., figs. 49–51).

Norma facialis.—The line of separation between the floor of the nose and the incisive region was a low, smooth ridge, the maxillo-nasal spine was moderate, the anterior nares were narrow, and the nasal index was leptorhine. The nasio-mental and maxillo-facial indices were leptoprosopic. The upper jaw was orthognathic. The upper orbital border immediately external to the supraorbital notch was thin, and receded so that the outer orbital process and malar border were in a plane distinctly behind the bridge of the nose, the nasio-malar index was 107·3, and the face, instead of being flattened, was approximately mesopic. The orbital aperture was rounded with a megaseme index. The palato-maxillary region was wide, and the index was brachyuranic. The lower jaw had a square chin. The teeth had all erupted, were but little worn, and not stained with betel.

The cranial sutures were simple; three small Wormian bones were in the lambdoid suture. The parieto-squamous was broad and with a small right epipteric bone. A thick sphenoidal rostrum occupied the concave upper border of the vomer. The jugal

TABLE V.

Tibetan Crania—Seistan Crania.

	Tibetan.		Seistan. Zahidan.		
Collection number,	Lhasa.	Kham. E. Tibet.	A.	B.	C.
Age,	Ad.	Ad.	Ad.	Ad.	Ad.
Sex,	M.	M.	M.	M.	F.
Cubic capacity,	1520	1430	1510	1385	1060
Glabello-occipital length,	179	184	179	183	170
Basi-bregmatic height,	132	141	142	139	132
Vertical Index,	*73·7*	*76·6*	*79·3*	*76·0*	*77·6*
Minimum frontal diameter,	98	96	91	100	86
Stephanic diameter,	122	105	119	115	90
Asterionic diameter,	...	107	115	108	96
Greatest parieto-squamous breadth,	142	137	148s.	144s.	128p.
Cephalic Index,	*79·3*	*74·5*	*82·7*	*78·7*	*75·3*
Horizontal circumference,	525	515	518	520	481
Frontal longitudinal arc,	136	127	129	130	123
Parietal ,, ,,	132	138	109	132	124
Occipital ,, ,,	114	109	125	104	...
Total ,, ,,	382	374	363	366	...
Vertical transverse arc,	...	300	324	320	280
Basal transverse diameter,	...	124	120	126	112
Vertical transverse circumference,	...	424	444	456	392
Length of foramen magnum,	34	40	38	36	...
Basi-nasal length,	93	100	105	107	94
Basi-alveolar length,	93	93	98	101	83
Gnathic Index,	*100*	*93·*	*93·3*	*94·4*	*88·3*
Total longitudinal circumference,	509	514	506	509	...
Interzygomatic breadth,	135	131	123	136	...
Intermalar ,,	121	118	110	119	105
Nasio-mental length,	...	122	...	...	...
Nasio-mental complete facial Index,	...	*93·1*	...	...	...
Nasio-alveolar length,	75	74	77	71	60
Maxillo-facial Index,	*55·5*	*56·4*	*62·6*	*52·2*	...
Nasal height,	53	53	52	48	46
Nasal width,	26	24	24	22	22
Nasal Index,	*49·1*	*45·3*	*46*	*45·8*	*47·8*
Orbital width,	36	38	36	40	35
Orbital height,	36	37	36	30	34
Orbital Index,	*100*	*97·4*	*100*	*75·*	*97·1*
Palato-maxillary length,	52	53	56	61	...
Palato-maxillary breadth,	62	63	68	...	...
Palato-maxillary Index,	*119·2*	*119·*	*121·2*	...	...
Nasio-malar Index,	*105·1*	*107·3*	*113·6*	*115·*	*106·7*
Lower jaw. Symphysial height,	...	30	...	...	...
Lower jaw. Coronoid ,,	...	62	...	...	...
Lower jaw. Condyloid ,,	...	65	...	...	...
Lower jaw. Gonio-symphysial length,	...	86	...	...	...
Lower jaw. Inter-gonial width,	...	93	...	...	...
Lower jaw. Breadth of ascending ramus,	...	37	...	...	...

processes of the occipital were tuberculated, and there was no 3rd condyl. The vertical index, 76·6, was hypsicephalic, and the height exceeded the breadth; the cephalic index, 74·5, was dolichocephalic; the breadth-height index was hypsistenocephalic. The intracranial capacity was 1430 c.c.

Physical Characters and Affinities of the Tibetans.

Although Tibet has for centuries been jealously guarded against access to Europeans, yet, before the recent British expedition, adventurous travellers had from time to time penetrated into the country, and a few had reached Lhasa, the capital. The physical characters of the people had to some extent been recognised by individual explorers; also by others, from opportunities of seeing Tibetans who had crossed the frontiers of India and China, and their affinities with the Mongolian type had been noted. An American traveller, Mr W. W. Rockhill, who, starting from Pekin, made two journeys through North-eastern and Eastern Tibet,* regarded the people as essentially of one race, the purest representatives of which were the semi-nomadic, pastoral, tent-dwelling tribes known as the Drupa type. In the towns and villages, again, the people were mixed with other Asiatic races, with the Chinese in the north and natives of India in the south and west. He defines the Drupa type as follows: stature about 5 feet 5 inches; head, brachycephalic; cheek bones, high; nose, thick; nostrils, broad; beard, thin; hair, long, coarse, tangled; skin, light brown, but dark brown when exposed to the weather. He traversed the province of Kham, which he writes K'am or K'ambo, from north to south-east, and saw men having the nose thin and aquiline, the eyes large and hazel, the hair long and wavy or curly, as a type common in Eastern Tibet, but which he had never observed in Central or Western Tibet. He says there is nothing Mongol about them, and that they are good representatives of old Tibetan civilisation, possibly descendants of the Tang-hsiang of the sixth century of our era.†

Accompanying the recent British expedition were several journalists‡ who wrote picturesque descriptions of the fighting and other incidents of the campaign, the appearance of the country, the monasteries and the Lamas, the dress and habits of the people, but without giving much information on their physical characters. Mr Edmund Candler, however, speaks of the people from the Kham province, who formed the bravest part of the Tibetan army, as wild, long-haired men, and he especially refers to Katsak Khasi as having comparatively aquiline features, which had not been "flattened out in youth."

* *The Land of the Lamas: a Journey made in* 1889, London, 1891. *Diary of a Journey through Mongolia and Tibet in* 1891 and 1892, Washington, 1894. *Reports of the United States National Museum*, 1893.

† Between the years 1895 and 1899 Mr and Mrs Rijnhart resided in the border country of China and Tibet, and also travelled in North-eastern and Eastern Tibet, following almost the same route as Mr Rockhill. See *With the Tibetans in Tent and Temple*, by Susie C. Rijnhart, M.D., Edinburgh, 1901. This book being written by a lady, gives glimpses of interest into the domestic life of the Tibetans. See also *Tibet, the Country and its Inhabitants*, by F. Grenard, pp. 72, 224, London, 1904, for an account of variations in the physical characters of the Tibetans.

‡ G. Candler, *The Unveiling of Lhasa*, London, 1905. Perceval Landon, *Lhasa, the British Mission*, London, 1905.

A fuller description of the people is given by Colonel L. A. WADDELL, C.B.,* who acted as the chief medical officer to the mission. He observed two distinct types, the one round-headed, broad, flat-faced, and oblique-eyed, approximating to the pure Mongol from the Steppes; the other longer headed, with nearly regular features, a fairly shaped long nose with a good bridge, and but little of the Kalmuk eye; this type, he says, approximates more to the Tartars of Turkestan and the nomads of the Great Northern Plateau (Hor). Colonel WADDELL noticed that a large number of the nobility and higher officials belonged to the longer-headed, longer-nosed type, and so strongly resembled the Muhammadan Balti coolies, from the country bordering the Pamirs, that they could scarcely be distinguished from each other.† He was told that recent migrations of these nomad Tartars had taken place into Southern Tibet, east of the Yamdok lake, near to the borders of Bhutan. In stature the Tibetans of Lhasa were even less than the Chinese, but the men from Kham were quite up to the standard of the Chinese. The people were generally light chocolate in colour, though many of the better class were almost as fair as a South Italian. The hair was black, and worn by the men in pig-tails, but in the women it was smoothly brushed and parted in the middle.

Advantage was taken of the presence of the expedition to explore both Central Tibet and the upper waters of the Brahmaputra river, an account of which has been given by Captain C. G. RAWLING.‡ He describes the nomads of Central Tibet as of short stature, the men averaging from 4 feet 11 inches to 5 feet, the women being considerably shorter. The complexion was a sickly olive, the teeth ill formed and frequently protruding. The men allowed their black, greasy hair to grow long and wild, only a few straggling hairs projected from the corners of the mouth, but the women usually wore the hair plaited and decorated. Tai-Tso, the chief man at Pomba, had a low forehead, a flat nose, an enormous mouth, and deeply pigmented eye-balls set in narrow slits. At Shigatse, the Tashi Lama, the functionary second in authority in Tibet, was visited, and is described as being exceptionally fair in complexion, with high cheek bones and finely chiselled features: the hands were extremely white and the fingers long and thin.

The two skulls, which, through Major WIMBERLEY's courteous attention, I have had the opportunity of examining, are of especial interest, as they illustrate the two types of Tibetans which Colonel WADDELL has described. The Mongolian type of the skull from Lhasa was shown in the broadly ovoid, brachycephalic, platychamæcephalic form of the cranium, the width of the forehead, the interorbital breadth, the low, flattened bridge of the nose, the wide anterior nares, the interzygomatic and intermalar breadth, the malar border of the orbit being in almost the same transverse plane as the bridge of the nose, and the slight degree of projection of the upper jaw.

* *Lhasa and its Mysteries*, London, 1905.

† Authorities are not agreed as to the characters of the people of Baltistan, a district to the north-east of Cashmere. Some regard them as showing a pronounced Mongolian type, others recognised Tibetan characteristics, whilst UJFALVY considered them to be almost Aryans (*Les Aryens*, by C. de Ujfalvy; Paris, 1896).

‡ *The Great Plateau*, London, 1905.

On the other hand the skull of the Kham warrior showed the longer-headed type. It was longer absolutely and also relatively to the breadth of the cranium than the Lhasa specimen, dolichocephalic and hypsistenocephalic. The bridge of the nose was not so wide or flattened and with a stronger profile, the anterior nares were narrower, the nasal index was leptorhine, the interorbital, intermalar, and interzygomatic breadths were less, the upper jaw was orthognathic and the cubic capacity was smaller. The cranial configuration of each skull was distinctive, and although only a single specimen of each type was under examination, the presence in Tibet both of a Mongolian and a longer-headed race was confirmed. The difference in the relation between the height and breadth of the cranium, which on previous occasions I have called attention to as not infrequently distinguishing the dolichocephali from the brachycephali, was present in these crania, for in the brachycephalic Tibetan the breadth was greater than the height, whilst in the dolichocephalic Kham warrior the height was greater than the breadth.

Some years ago Mr H. H. Risley published elaborate tables of measurements of natives of Bengal, taken by an assistant under his supervision during 1886–7–8.* These tables included measurements of Tibetans arranged under three heads, Tibetans of Tibet, of Sikkim, and of Bhutan. In stature the Tibetans of Tibet averaged 164·2 c.m., those of Sikkim 162·9 c.m., those of Bhutan 162·1 c.m., and the mean range therefore was from 5 feet $3\frac{3}{4}$ inches to 5 feet $4\frac{1}{2}$ inches. The indices computed from certain measurements of the head and face are given below.

Tibetans of Tibet.	Of Sikkim.	Of Bhutan.
Cephalic Index.		
20 from 80 to 88·9 6 „ 77·5 „ 79·9 9 „ 75 „ 77·5 2 at 72·9 and 74·2 37, Mean of the series, 80·5	29 from 80 to 93·2 4 „ 78·1 „ 79·5 1 at 77·2 34, Mean, 82·7	9 from 80 to 91·2 5 „ 77·5 „ 79·9 4 „ 75 „ 77·5 1 at 72·6 19, Mean, 80·2
Nasal Index.		
9 from 81·1 to 90·3 13 „ 70·3 „ 79·6 14 „ 62·5 „ 70 26	2 were 81·8 and 86 18 from 71·1 to 78·8 13 „ 61·8 „ 69·8 1 was 58·4 34	3 from 91·1 to 102·6 6 „ 80 „ 86·9 7 „ 70·1 „ 79·1 3 „ 64·8 „ 65·3 19
Nasio-Malar Index.		
13 from 110·1 to 113·3 15 „ 107·9 „ 109·8 6 „ 103·4 „ 107·4 34	10 from 110 to 112 13 „ 107·5 „ 109·7 8 „ 103·2 „ 107·4 31	2 from 113·3 to 115 5 „ 107·5 „ 109·4 3 „ 105·8 „ 107·2 10

* *The Tribes and Castes of Bengal, Anthropometric Data*, vol. i. p. 273, *e.s.*, Calcutta, 1891.

An inspection of the above table shows that a wide range of variation in all these indices was found in the persons measured. The cephalic index in the Tibetans of Tibet ranged from below 75 in two skulls to 80 and upwards, 88·9, in twenty specimens, *i.e.* from definite dolichocephalic to hyperbrachycephalic proportions. In the Tibetans of Bhutan the range was equally great, but in the Tibetans of Sikkim no head was dolichocephalic. In each of the three groups the mean index was brachycephalic, especially in the Sikkim Tibetans, and the rounded form of head preponderated. The presence, however, of a small proportion of heads either dolichocephalic or in the lower term of the mesaticephalic group, leads one to think that the assistant who made the measurements had in some cases included persons whose race characters had not been discriminated with sufficient exactness, a conclusion which is also supported by the analysis of the nasal indices,* which ranged from platyrhine, 85 and upwards, to leptorhine below 70, and of the nasio-malar indices which proved the presence of a platyopic Mongolian type as well as pro-opic faces approximating to the Caucasian form.

Subsequently to the appearance of Mr Risley's tables, Lieut.-Col. Waddell published some measurements made by himself of eight Tibetans from the lower Tsang-po.† The mean stature was 5 feet $4\frac{1}{4}$ inches, the mean cephalic index was 81·3, and the mean nasal index 82·2. The lowest cephalic index was 77·7, the highest 86·1; five were above 80 and three in the upper term of the mesaticephalic group. The brachycephalic and mesorhine character of these people therefore was distinct.

Whilst there is no difficulty in associating the Tibetans generally with the Mongolian type of head and face, the affinities and derivation of the long-headed people of the Kham province will require more consideration. The position of this province in the east of Tibet brings it into relation with the ranges of mountains at the north of Burma, in which arise the great rivers that flow south into the Bay of Bengal, as well as with the Brahmaputra as it bends north and west to reach the north base of the Himalayas and to join apparently the Tsang-po river in the province of Lhasa in Tibet. This extensive range of country is occupied by people speaking closely connected languages and dialects, which philologists name the Tibeto-Burman stock.

Mr G. A. Grierson has contributed to the recently published *Census of India* an important chapter on the Languages of India.‡ He regards the Tibeto-Burman stock as a subfamily of the Indo-Chinese group, the original home of which was probably North-western China, between the upper waters of the Yang-tse-Kiang and the Ho-ang-ho. From the Tibeto-Burman stock of people one branch, he says, entered Tibet, offshoots from which settled on the southern slopes of the Himalayas; others followed the course of the Brahmaputra as far south as the Garo Hills and Tipperah; others occupied the

* The division of the nasal index, computed from measurements during life, is as follows: leptorhine, below 70; mesorhine, 70–85; platyrhine, 85 and upwards. In the skull itself the division is leptorhine below 48; mesorhine, 48–53; platyrhine above 53.

† "The Tribes of the Brahmaputra Valley," *Journal of the Asiatic Society of Bengal*, vol. lxix. part iii. 1900, Calcutta, 1901.

‡ *Census of India*, 1901, vol. i. part 1, by H. H. Risley, C.I.E., and E. A. Gait, I.C.S., Calcutta, 1903.

Naga Hills, the valley of Manipur, and the head-waters of the Chindwin and Irrawaddy rivers. From the last-named region offshoots colonised the Chin Hills, Lushai land, Cachar, and the valley of the Irrawaddy, and a swarm called the Tai conquered the mountainous country to the east of Burma.

It will therefore be of interest at this stage to consider the physical characters of the people living in the Tibeto-Burman region, and the configuration of their skulls. Although the tribes occupying the mountains are warlike savages, so that opportunities for observation and the acquisition of specimens occur only occasionally, yet some facts are at our disposal.

Through the courtesy of several of my former pupils, I was able to examine and describe, in Part I. of this series of memoirs,* nineteen skulls of the Naga, Chin, and Lushai mountaineers, and I would refer to it for a detailed description. Six Naga skulls, six Chins, and three Lushais were either dolichocephalic or approximated thereto, and may fitly be compared with the skull from the Kham province.† As with the Kham skull the terms elongated and ovoid apply to the outline of their crania in the *norma verticalis*, though in some the breadth in relation to the length was greater than in others. In the Kham specimen the upper jaw was orthognathic, a character present in the majority of the mountaineers. The face was broad, and in the Kham skull the interzygomatic diameter was 131 mm., something more than the mean of the Chin-Lushais, 127, but not quite so great as the mean of the Nagas, 134. In the Kham the nasio-malar index was 107·3, in the mountaineers it ranged from 104·8 to 110, with the mean 107·5 : a close correspondence therefore existed in the degree of projection of the bridge of the nose beyond the plane of the malar borders of the orbits. In the Kham skull the nasal index was leptorhine, in the mountaineers four were leptorhine, seven mesorhine, four platyrhine, a range of variation which, through paucity of specimens, could not be determined amongst the Khams. As the features of resemblance correspond in so many important respects in the skull of the Kham with those of the people of the Naga, Chin, and Lushai Hills, craniology lends support to the opinion, based on affinities of language, that they belong to a common stock, for the points of difference are no greater than may be found in the skulls of people of the same race (Pl. X., figs. 51–53).

In further extension of this question I may refer to two skulls obtained in an old cemetery in Upper Burma, also described in Part I. of this series of memoirs,‡ in which the dolichocephalic form and proportions and the mean leptorhine nasal index, at once distinguished them from the brachycephalic type of the modern Burmese people. These skulls therefore in all probability may be regarded as representing the offshoot of the Tibeto-Burman stock, which, many centuries ago, penetrated into Burma from the mountainous districts to the north, and in course of time became to a large extent displaced by a brachycephalic people, allied in all probability to the Shans and Chinese.

* *Trans. Roy. Soc. Edin.*, vol. xxxix. p. 703, 1899.

† Two Nagas, and two from the South Lushai Hills, were brachycephalic, and are not included in the comparison.

‡ *Op. cit.*, p. 736, pl. iii. fig. 14.

Since the publication of Part I., Colonel WADDELL's memoir on the *Tribes of the Brahmaputra Valley* has appeared, and additional observations and measurements taken by himself are now available for comparison. The *Abors* at the north-east extremity of the Brahmaputra valley, the *Arlengs* between the south bank of the Brahmaputra and the Kachar Hills, the *Bhotiyas* of Bhotan from the eastern end of the Himalayas, the *Kachari* or *Bodos* in the central Brahmaputra valley, the *Kasia* in Assam, the *Khumbu* and *Khiranti* of Eastern Nepal, the *Koch* between lower Assam and North-eastern Bengal, the *Kukis* from the Kuki-Lushai Hills, the *Mandé* or *Garo* in the mountains between Burma and the Brahmaputra, the *Mishing* or *Miri* on the north bank of that river up to the Dihong, the *Lepchas* or *Rong* from the Sikkim Himalayas, are all stated to have Mongoloid features. They are by no means uniform in the relations of the length and breadth of the head, or in that of the height of the nose and width of the nostrils, as is shown in the following table, which states the mean of Colonel WADDELL's measurements :—

	Ceph. Index.	Nasal Index.	Stature.
Abor,	77·2	90·7	5 ft. 2 in.
Arleng,	77·9	85·1	5 „ 4¼ „
Bhotiyas,	80·3	77·1	5 „ 3¼ „
Kachari,	78·5	88·1	5 „ 3 „
Kasia,	78·7	86·4	5 „ 1½ „
Khumbu,	82·4	85·7	5 „ 2¼ „
Koch,	76·8	80	5 „ 2½ „
Kukis,	76·5	91	5 „ 2¼ „
Lepchas,	80·6	78·3	5 „ 2 „
Mandé,	76	95·1	5 „ 2¼ „
Mishing,	80·9	84	5 „ 1½ „

In the account which I gave in Part I. of the natives of the Chin, Lushai, and Naga Hills, I quoted statements made by those who had travelled amongst them, and especially referred to the Mongoloid characters of the face so frequently described. I also quoted the remark made by Colonel LEWIN, that amongst the Lushais were faces not bearing marks of Mongolian descent, whilst Colonel WOODTHORPE stated that the Angami Nagas had sometimes aquiline features and fair, ruddy complexions.

In my description of the Chins, Lushais, and Nagas I directed attention to the presence of a Mongolian type of feature in certain hill tribes where the customary form of skull was dolichocephalic or approximated thereto, so that the Mongoloid face was not therefore exclusively associated with the brachycephalic form of skull. Colonel WADDELL's measurements require to be examined in their bearing on this question. The cephalic index of the heads of persons whose Mongoloid features were recognised by so trained an observer, ranged from 76 to 82·4, and the nasal index ranged from 78·3 to 95·1. As the cephalic index computed from measurements of living persons is higher than if taken from the skull itself, had the index in the same persons been computed from the skull, it would probably have ranged from 74 to about 80, which would have included all the three groups into which skulls are arranged in accordance with

differences in this index. As the width of the nostrils is much greater than that of the anterior nares, whilst the height of the nose is little more when measured in the face than in the skull, the nasal index computed from the face is necessarily materially greater than when obtained by measuring the skull. Many therefore of the people of these tribes would have had skulls whose proportions were dolichocephalic or approximated thereto, and WADDELL'S observations on living persons are confirmatory of the conclusions which I had previously formed from the study of the skull.

SEISTANIS. TABLE V.

In the year 1903 an expedition, under the command of Sir ARTHUR H. MACMAHON, K.C.I.E., was despatched by the Government of India to Seistan to act as an arbitration Commission to adjust the boundary between Persia and Western Afghanistan, and the distribution of the water of the Helmand river. Major T. WALTER IRVINE, I.M.S., was the medical officer in charge, and he collected on the site of the ancient city of Zahidan three human skulls, buried under a mound of sand frequently shifting through the prevalence of strong winds. Two of these were sent by him to Professor CHIENE of Edinburgh, who presented them to the University Museum, and the third was forwarded to the Anthropological Institute of London, from whom I received it. Zahidan, from the extensive ruins which mark its site, had evidently been a city of great importance and the seat of a bygone civilisation. It was destroyed by Timour during his advance into India in 1367. It is also interesting to note that Seistan was on the route followed by Alexander the Great and the Greeks in the famous march to the Indus, when he invaded India in 327 B.C.

The skulls were those of adults, two males, A and B, and one female, C; the lower jaw was absent in each specimen. The males differed materially in character from the female, and require a separate description. They were massive skulls, well proportioned, and unusually heavy: A weighed 1 lb. $9\frac{1}{2}$ oz., B 1 lb. $15\frac{3}{4}$ oz.

Norma verticalis.—In A the outline was rounded, and the cranium was of such a breadth, 148 mm., that though the length was 179 mm., the cephalic index was 82·7, distinctly brachycephalic. B had not the outline so rounded, for the breadth was less, and the length, in part owing to the prominent glabella, was 183 mm.; the cephalic index therefore was 78·7, in the higher term of the mesaticephalic group. The outline in both from side to side across the vertex was a wide, rounded arch. The sagittal region was not ridged, the parietal eminences were fairly distinct, and the side walls bulged in the squamous region. The parieto-occipital surface sloped steeply downwards, without sign of artificial flattening. The skulls were cryptozygous.

Norma lateralis.—In A the frontal eminences were prominent, the forehead was only slightly inclined backwards, the glabella and supraorbital ridges were moderate and the nasion was not depressed. In B the frontal eminences were distinct, the slope of the forehead was more marked, the glabella and supraorbital ridges were very

prominent, and the nasion was much depressed. The bridge of the nose was 15 mm. long in A, a little longer in B, and in both slightly concave, sharp, projecting, and not flattened. The interorbital diameter in A was 24 mm., in B 26 mm. In A the parietal longitudinal arc was much the shortest, and the frontal slightly exceeded the occipital. In B the occipital was short and the frontal and parietal longitudinal arcs were almost equal. In A the cranium rested behind on the cerebellar fossæ of the occiput, in B on the mastoids (Pl. XI., figs. 55–57).

Norma facialis.—In both skulls the nasal floor was separated by a sharp ridge from the incisive fossæ, which, as well as the canine fossæ, were markedly hollow. In both the maxillo-nasal spine was strong. The height of the nose was more than double the width of the anterior nares, and the nasal index was leptorhine. In A, owing to the height of the maxilla and the flattened zygomata, the maxillo-facial index was remarkably high, and both skulls were leptoprosopic. The upper jaw was orthognathic. In A the orbital aperture was rounded and megaseme, but in B, owing to the development of the supraorbital ridges, the height of the aperture was diminished and the index was microseme. In A the palato-maxillary arch was very deep, 17 mm. opposite the 2nd molar tooth, the arch was wide, and the maxillo-premaxillary suture was distinct. The teeth were partially worn and not stained with betel. In B the arch was more elongated and comparatively shallow, but the molar alveoli were absorbed.

In both the male skulls some small Wormian bones were in the lambdoid suture. The other sutures were moderate in the denticulation. In A they were not obliterated, in B they were partially ossified: in both the parieto-squamous sutures were broad and there were no epipteric bones. In A the spinous processes were ossified to the temporals. In both the mastoids were massive, there was no 3rd condyl or paracondylar processes, and the inion and curved lines were moderate. In both the vertical index was hypsicephalic; in each skull the height was less than the breadth, and the corresponding index was platychamæcephalic. Though in B the cephalic index was less than the lower brachycephalic limit, the skull in its general form and characters approximated much more to the brachycephali than to the dolichocephali. The cranial capacity of A was 1510 c.c., of B 1385 c.c.

Skull C was to all appearance that of a woman. It was much smaller than A and B, the parietal eminences were prominent, the mastoids and inion were feeble, and the orbital borders were sharp. Although the cerebellar part of the occiput and the left zygomatic arch were broken off and lost and the lower jaw was absent, this small skull was unusually heavy and weighed 1 lb. $9\frac{1}{4}$ oz., or within $\frac{1}{4}$ oz. of the male skull A.

Norma verticalis.—The cranium was elongated, pentagonal in outline, and relatively narrow: the cephalic index was 75·3, essentially dolichocephalic, though fractionally higher than its numerical limit. The breadth, owing to the projecting eminences, was greatest in the parietal region, the sagittal line was somewhat elevated in front, though grooved behind the obelion, and the slope outwards from it gave a roof-like character

to the vertex. The parieto-occipital slope was gradual, and the occipital squama projected behind the inion. The zygomatic arches were flattened, and the skull was cryptozygous. The stephanic diameter was 6 mm. less than the asterionic.

Norma lateralis.—The forehead inclined backwards and upwards, the glabella and supraorbital ridges were moderate; the nasion was not depressed; the bridge of the nose was 19 mm. long, straight, feebly projecting though not flattened; the interorbital diameter was 22 mm. The cranium rested behind on the cerebellar occipital fossæ. The frontal and parietal longitudinal arcs were almost equal; the injury to the occipital bone did not admit of the occipital arc being measured (Pl. XI., figs. 58–60).

Norma facialis.—The floor of the nose was separated from the incisive region by a sharp ridge: the maxillo-nasal spine was moderate. The height of the nose in proportion to the width of the nares was less than in A, and the nasal index, 47·8, was leptorhine; the canine fossæ were deep; the upper jaw was not projecting, and the index was orthognathous, 88·3. The orbital borders were sharp, and the aperture was roundish and megaseme, 97·1. The palato-maxillary arch was shallow, and too much injured to measure. The teeth had been lost.

The cranial sutures were on the whole simple, and not obliterated; the parieto-squamous were broad; the left asterion had a Wormian bone. The spinous processes were not ossified to the temporals. No special variations were noted. The vertical index, 77·6, was hypsicephalic, and higher than the cephalic index, 75·3, which was fractionally above the numerical dolichocephalic limit; the breadth-height index was hypsistenocephalic. The cranial capacity of C was low even for a woman, only 1060 c.c., but the dimensions generally of the skull were small and indicated a person of low stature.

It is not possible definitely to associate the skulls collected by Major Irvine with the races to which they belonged. Seistan, from its relation to the frontiers of Persia, Afghanistan, and Baluchistan, is liable to have its people intermingled with Persians, Afghans, and Baluchis. Further, the country, having been subjected to successive invasions from the north, other tribes and races may have settled there. Neither is it possible to state definitely to what period the skulls should be referred. They were found lying loose in a mound of sand, and apparently without any objects along with them which could give a key to their age. As is well known, dry sand is a remarkable preservative of bones, and from their bleached appearance they had probably at times, when the sand shifted, been exposed to the sun. As they were found on the site of the city of Zahidan, which was destroyed more than five hundred years ago, they might have been the skulls of its ancient inhabitants; but on the other hand they might have belonged to people who in much more recent years had camped on the site.

The evidence of the race and date of burial being therefore so incomplete, one has, in attempting to discriminate their history, to rely upon the characters of the skulls themselves.

The males belonged to large-brained people, with massive heads, brachycephalic, or approximating thereto. The nose was not flattened, the nasal index was low, the face

was high, and the nasio-malar index, 114, gave a projecting pro-opic character to the profile. Although the locality in which they were found and the brachycephalic form of the cranium would lead one to think that they might have had racial affinities with the Mongolians, the facial characters showed a definite departure from the Mongolian type. In the female, again, the elongated skull, its dolichocephalic proportions, low nasio-malar index, 106·7, and platyopic face, presented differences from the males much more than could be regarded as sexual, and seem to justify the conclusion that it was of another race.

As regards the Baluchis, or Bilochs, Mr Risley's table * of measurements of sixty men show that in thirty-two the cephalic index exceeded 80, in one of which the index reached 95·4; in twenty-two the index ranged from 75·5 to 79·4, ten of which were above 77·5, whilst six were below 75. The prevailing type was brachycephalic or approximated thereto. The nasal index was leptorhine. The nasio-malar index was high, and averaged 117·9.

Measurements taken by Mr John Gray of the heads of the Indian soldiers † who were in London at the time of the Coronation, may perhaps assist in throwing further light on the affinities of these crania from Seistan. Mr Gray found that the Afridis had a mean cephalic index 74·2, the Afghans 76·3, the Muhammadan Punjabis 72·7, the Sikhs 73·1, all of whom therefore had dolichocephalic heads. The dolichocephalic skull C may possibly be that of an Afghan or Afridi woman.

On the other hand the Baluchi soldiers, thirteen in number, measured by Mr Gray, had the mean cephalic index 83·4. When the necessary reduction is made for the thickness of the soft parts, this index closely approximates to the mean of the skulls A and B in this description, and expresses the brachycephalic character, though much less pronounced than in the Mongolian inhabitants of Central Asia. When it is kept in mind that the Baluchis, owing to the uncertain water supply, the character of the climate, and the conformation of their country, are a nomadic people, it is not unlikely that they may frequently cross the frontier into Seistan, and their skulls consequently be occasionally found in that province.

Sagittal Sections—Tables VI., VII.

In previous memoirs on the skull published in the *Challenger Reports* and in the *Transactions* of this Society,‡ I have reproduced tracings of sagittal sections which showed the contour of crania near the mesial plane. Lines radiating from the basion were drawn to definite anatomical points on the surface of the skull, also other lines which at their intersections enabled angles to be measured. In this memoir similar

* *Tribes and Castes of Bengal, Anthropometric Data*, vol. ii., Table I., p. 815.

† *Man*, iii. p. 69, 1903.

‡ *Challenger Reports*, part xxix., 1884; *Trans. Roy. Soc. Edin.*, vol. xl. part i., 1901; part iii., 1903.

sections of additional skulls are given with radial and other lines and measurements. As suggested in my paper on *Pithecanthropus erectus*,* an antero-posterior nasio-tentorial plane, from the nasion to the upper border of the groove for the lateral sinuses,† expressed the division of the cranial cavity into an upper cerebral part, occupying the large space above the tentorium, orbital plates of the frontal, cribriform plate of the ethmoid and great wing of the sphenoid; and a basal part in which the cerebellum, pons, and medulla are lodged. The division of the radial lines by the line *nt*, which indicates the nasio-tentorial plane, marks off the upper cerebral part from the lower basal part, and the diameter of the cavity where each radial line touches the inner table of the skull is stated in Table VI. Further, a line drawn from the nasion to the bregma *nbr*, as has been done by Professor CUNNINGHAM,‡ gives the chord of the arc of the frontal bone; the depth of the arc is measured by erecting a perpendicular from the chord to the most projecting part of the frontal, whilst the depth of the cerebral space, which the chord and arc enclose, is obtained by measuring the length of this perpendicular to the point where it touches the inner table of the bone. The fronto-occipital diameter of the cerebral cavity, and the diameter of the cavity from the perpendicular radius to the frontal and occipital poles respectively, are given in Table VI. The lines intersecting the cranial cavity subdivide it into regions which indicate approximately the position and relative magnitude of important divisions of the brain. The area of the cerebrum below is defined generally by the nasio-tentorial plane. Though the plane of the foramen magnum, from which the perpendicular radius is drawn at right angles, varies in its inclination in different skulls, and is not necessarily parallel to the horizontal plane of the head, the tentorio-perpendicular section of that radius has a general relation to the fissure of Rolando and to the posterior limit of the frontal lobe. The space between the tentorio-perpendicular and tentorio-lambdal radii is associated with the parietal and upper part of the temporal lobes, and the region behind the tentorio-lambdal radius with the occipital lobe. The influence exercised by the frontal sinus on the curvature of the inner and outer tables is shown in the figures reproducing the sections, as well as the extent of the air sinus above the glabella. For purposes of comparison Table VI. includes corresponding measurements of some of the skulls described in Part II. of this series of memoirs,§ details of which were not at that time given, also measurements of sagittal sections of two skulls described in my memoir on the Craniology of the People of Scotland.‖

* *Journ. Anat. Phys.*, vol. xxix. p. 424, 1895.

† The inion on the outer table is, as a rule, lower down than the upper border of the groove for the lateral sinus on the inner table which marks the attachment of the tentorium, hence the term nasio-tentorial plane is to be preferred to nasio-inial plane.

‡ "The Brain of the Microcephalic Idiot," *Scientific Transactions of the Royal Dublin Society*, vol. v. p. 344, fig. 16, 1895.

§ The Veddah, Gond, Múnda, Bhúmij, and Pan Cole skulls are described and measured in Part ii., Tables i., iii., iv., ix., *Trans. Roy. Soc. Edin.*, vol. xl., 1901.

‖ *Trans. Roy. Soc. Edin.*, Tables iii., xiii., xvii., 1903.

Table VI.

Sagittal Sections.

	Tamil Sudra, K. C. Ix. 74·3. Fig. 61.	Thug, 130. C. Ix. 75·4. Fig. 62.	Thug, 131. C. Ix. 74. Fig. 63.	Veddah, A. C. Ix. 67. Figs. 27, 64.	Gond, A. C. Ix. 69·4.	Múnda, I.M. 26. C. Ix. 70·9. Fig. 36.	Bhúmij, I.M. 18. C. Ix 72·7. Figs. 20–22.	Pan Cole, I.M. 55. C. Ix. 73·8.	Mid-Lothian, Rx. C. Ix. 80·1.	Shetland. C. Ix. 75·1.
Basi-inial radius,	76 mm.	76 mm.	79 mm.	75 mm.	71 mm.	78 mm.	80 mm.	78 mm.	89 mm.	91 mm.
,, -occipital radius,	100 ,,	103 ,,	95 ,,	98 ,,	104 ,,	94 ,,	107 ,,	109 ,,	104 ,,	116 ,,
,, -lambdal, ,,	115 ,,	112 ,,	110 ,,	107 ,,	110 ,,	116 ,,	113 ,,	122 ,,	117 ,,	123 ,,
,, -perpendicular radius,	143 ,,	132 ,,	131 ,,	128 ,,	139 ,,	133 ,,	133 ,,	125 ,,	136 ,,	145 ,,
,, -bregmatic radius,	141 ,,	130 ,,	132 ,,	127 ,,	139 ,,	128 ,,	131 ,,	126 ,,	134 ,,	141 ,,
,, -glabellar ,,	104 ,,	109 ,,	104 ,,	107 ,,	113 ,,	111 ,,	103 ,,	110 ,,	105 ,,	118 ,,
,, -nasial ,,	94 ,,	105 ,,	96 ,,	98 ,,	104 ,,	101 ,,	95 ,,	101 ,,	99 ,,	110 ,,
,, -alveolar ,,	90 ,,	97 ,,	95 ,,	100 ,,	102 ,,	95 ,,	92 ,,	99 ,,	91 ,,	...
Nasio-tentorial plane,	167 ,,	167 ,,	165 ,,	171 ,,	170 ,,	171 ,,	175 ,,	176 ,,	172 ,,	191 ,,
Tentorio-bregmatic line,	97 ,,	90 ,,	90 ,,	81 ,,	96 ,,	84 ,,	96 ,,	88 ,,	89 ,,	99 ,,
,, -perpendicular line,	98 ,,	92 ,,	91 ,,	81 ,,	97 ,,	90 ,,	98 ,,	86 ,,	93 ,,	106 ,,
,, -lambdal line,	61 ,,	62 ,,	56 ,,	54 ,,	56 ,,	65 ,,	68 ,,	73 ,,	62 ,,	77 ,,
,, -occipital ,,	24 ,,	47 ,,	22 ,,	27 ,,	45 ,,	19 ,,	63 ,,	43 ,,	37 ,,	62 ,,
Nasio-bregmatic chord,	111 ,,	108 ,,	106 ,,	106 ,,	112 ,,	97 ,,	116 ,,	110 ,,	109 ,,	120 ,,
Perpendicular therefrom to outer table of frontal,	29 ,,	22 ,,	28 ,,	27 ,,	27 ,,	21 ,,	31 ,,	29 ,,	27 ,,	28 ,,
The same to inner table,	23 ,,	16 ,,	21 ,,	18 ,,	18 ,,	17 ,,	25 ,,	19 ,,	22 ,,	21 ,,
Fronto-occipital diameter of cerebral cavity,	158 ,,	151 ,,	160 ,,	162 ,,	160 ,,	162 ,,	168 ,,	166 ,,	161 ,,	179 ,,
From perpendicular radius to frontal pole of cavity,	83 ,,	84 ,,	88 ,,	91 ,,	86 ,,	89 ,,	94 ,,	88 ,,	82 ,,	93 ,,
From perpendicular radius to occipital pole of cavity,	75 ,,	67 ,,	72 ,,	71 ,,	74 ,,	73 ,,	74 ,,	78 ,,	79 ,,	86 ,,

The measurements obtained from the sagittal sections enable one to ascertain the diameters of the cerebral portion of the cranial cavity in two dimensions; the diameter between the frontal and occipital poles gives the length, whilst the tentorio-bregmatic, -perpendicular, -lambdal, and -occipital diameters give the height in the named regions. Although the third or breadth dimension cannot be obtained from the sections, the two dimensions which have been measured will give some conception of the length and height of the cranial cavity occupied by the cerebrum.

The length and collective height dimensions separately stated are as follows:—

	Tamil.	Thug, 130.	Thug, 131.	Veddah.	Gond.	Múnda.	Bhúmij.	Pan Cole.	Mid-Lothian.	Shetland.
Length,	158	151	160	162	160	162	168	166	161	179
Height,	280	291	259	243	294	258	325	281	281	344
Total,	438	442	419	405	454	420	493	447	442	523

Eight of these crania are from natives of India and Ceylon, and, with the possible exception of the Thugs, are Dravidians. They range in the length-height diameters from 405 in the Veddahs to 493 in the Bhúmij skull.

In one of the Thugs, No. 130, these diameters were equal to the same measurements in the Mid-Lothian skull, but, as the latter was brachycephalic, its breadth was greater in the frontal and parieto-squamous regions, and the cubic capacity was 1440 c.c. as compared with 1218 in the Thug.

The perpendicular line drawn from the nasio-bregmatic chord to the inner table of the frontal arc in the Bhúmij skull, in which the frontal region was well arched, was 25 mm. In the Veddah, Gond, Múnda, and Pan Cole crania it was below 20; in the Thug, No. 130, in which the forehead was retreating, it was only 16 mm.; but in No. 131 it was 21 mm., which, as well as the length to a point on the outer table, was the same as the corresponding diameters in the large Shetland cranium.

Attention has been called by craniologists to the relation of the three factors which make up the longitudinal circumference of the skull. Two of these, viz. the length of the foramen magnum and the basi-nasal diameter, together constitute the base line of Cleland,* and their proportion to the total longitudinal arc has been estimated. In this memoir I have made a similar calculation, which is embodied in Table VII., and I have added, for purposes of comparison, dimensions of Scottish and Australian skulls given in my memoir on Scottish crania.†

Table VII.

	Tamil Sudras.	Pariahs.	Badaga.	Thugs.	Veddahs.	Lhasa.	Kham.	Seistanis. A. B.	Scottish.	Australian.
‡ Mean base line, .	132·3	134·2	135	133	130	127	140	143	134·3	139·8
„ longitudinal arc, . .	362·4	357·7	376	364	360	382	374	364·5	376·5	380·4
„ longitudinal circumference, .	494·7	492·	511	497·3	491	509	514	507·5	510·8	520·2
„ base line to long. arc, . .	2·7	2·6	2·78	2·7	2·7	3·	2·6	2·5	2·8	2·7
„ base line to long. circumference,	3·7	3·6	3·78	3·7	3·7	4·	3·6	3·5	3·8	3·7

The range in the proportion of base line to the longitudinal arc varied from 3 in the Lhasa to 2·5 in the Seistani, the latter of which had relatively the longest base line. The Lhasa skull in the proportion of the arc to the base line was considerably greater than in the skull from the Kham province and than the mean of the Scottish skulls. Little variation existed in the proportion of base line to arc in the Indian crania, Tamil Sudras, Pariahs, Badaga, Thugs and Veddahs, which were approximately 2·7, about the same figure as in the Australian crania. The proportion of the base line

* Cleland, *Philosophical Transactions*, p. 122, 1869, Cunningham, *Transactions Royal Dublin Soc.*, vol. v. 1895.

† Turner, *Trans. Roy. Soc. Edin.*, vol. xl. part iii., 1903.

‡ Where the number permitted more than one skull to be measured, the mean of the group is given in the Table.

in Thug No. 130, with the retreating forehead, was 2·6, whilst in No. 131, in which the forehead was more highly arched, the proportion of base line was 2·7.

ADDENDUM, 29*th June*.—Since this memoir was read, Professor CUNNINGHAM has called my attention to the skeleton of a Tamil Sudra from Mysore, which was presented to him for the Museum early in June, by Mr R. B. THOMSON, M.B. It had been brought from Madras by an Indian student from the College of Medicine in that city.

The skeleton was a male, in which the ossification was completed, though the wisdom teeth had not erupted. The skull was elongated, ovoid, dolichocephalic, Ceph. Ix. 71. The glabella and supraorbitals were well marked, the nasion was depressed, the sutures were unossified, the pterion was normal, and the muscular ridges and processes were distinct. A special feature was the large interparietal bone which took the place of the occipital squama above the inion and superior curved lines. The occipital condyls were deeply cleft at the inner border; the posterior condylar foramina were absent; a pair of stunted processes projected downwards from the basi-occipital immediately in front of the basion. The basi-bregmatic diameter exceeded the greatest breadth, and the vertical index was 73·7. The upper jaw was orthognathic, 95. The complete facial index, 94·5, and the maxillo-facial index, 51·1, were leptoprosopic. The bridge of the nose was moderate, the nasio-malar index being 109; the nasal index, 49·9, was mesorhine. The orbital index was microseme, and the palato-maxillary index was hyperbrachyuranic.

The pelvis had distinct male characters. The iliac bones were expanded and the fossæ were translucent; the tubercle on the crest and the muscular ridges were moderate; the præauricular sulcus was a shallow groove. The cotyloid notch was wide, the pectineal crest and pubic spine were moderate. The body and neural arch of the first sacral vertebra were not fused with the second. The neural arches of the 2nd, 3rd, and 4th sacrals formed a continuous plate. The first coccygeal vertebra was fused with the body of the 5th sacral, and in each of these bones the cornua were strong though not continuous with each other. The following measurements were taken:—

Measurements of Pelvis.

	mm.
Height of pelvis,	244
Breadth „	193
Breadth-Height Index,	*79*
Between anterior superior iliac spines,	218
„ posterior „ „ „	71
„ outer borders of ischial tubera,	136
Vertical diameter of obturator foramen,	49
Transverse „ „ „	34
Obturator Index,	*69·4*
Subpubic angle,	67°
Transverse diameter of pelvic brim,	106
Conjugate „ „	102
Pelvic or Brim Index,	*96*
Length of sacrum,	101
Breadth „	102
Sacral Index,	*100·9*

The pelvis was broad in relation to the height, and the corresponding index was low. The sides of the pelvic brim were smooth, and as the conjugate diameter was high in relation to the transverse, the brim index, 96, was dolichopellic. The length of the sacrum did not include the body of the first coccygeal vertebra, and the index, 100·9, was platyhieric. The obturator index, 69·4, was intermediate between that in the Bagada and Veddah pelves.

Spinal Column.—The vertebral formula was $C_7 D_{12} L_5$. The spine of the 6th cervical was almost as prominent as that of the 7th; the spines of the 3rd, 4th, and 5th were bifid. The 9th dorsal had only a half costal facet on each side of the body, and the 10th, 11th, and 12th had each a whole facet; the 10th had no costal facet on the transverse process; the 11th and 12th had each three tubercles and no long transverse process. The lumbars were normal. The diameters of the bodies of the lower dorsals and lumbars were as follows:

	A.V.D.	P.V.D.	Index.	
9th Dorsal V., . . .	20 mm.	20 mm.	100	Special Index.
10th ,, ,, . . .	20 ,,	21 ,,	105	
11th ,, ,, . . .	20 ,,	22 ,,	110	
12th ,, ,, . . .	21 ,,	24 ,,	114·3	
	81 mm.	87 mm.	107·4	General Index.
1st Lumbar V., . .	26 mm.	23 mm.	88·4	Special Index.
2nd ,, ,, . .	23 ,,	24 ,,	104·3	
3rd ,, ,, . .	23 ,,	24 ,,	104·3	
4th ,, ,, . .	23 ,,	24 ,,	104·3	
5th ,, ,, . .	25 ,,	22 ,,	88·	
	120 mm.	117 mm.	97·5	General Index.

The indices of the bodies of the 9th, 10th, and 11th dorsal vertebræ showed that the upper and lower surfaces were almost parallel, but in the 12th the posterior vertical diameter was definitely higher than the anterior. The 1st lumbar presented the unusual character of the anterior vertical diameter, being distinctly higher than the posterior; in the 2nd, 3rd, and 4th it was slightly less; but in the 5th, as is customary, the anterior exceeded the posterior. The bodies of the 1st and 5th therefore in this spine contributed to produce an anterior lumbar convexity, or a kurtorachic spine.

The *Ribs* were twelve pairs. The *Sternum* articulated with twelve pairs of costal cartilages; the xiphi-sternum was ossified and fused with the meso-sternum, the manubrium was free, and not quite symmetrical on the two lateral borders.

The Upper Limb.—The *Clavicles* were slender and not strongly curved. The *Scapulæ* had wide, shallow, coracoid notches; the axillary border was somewhat concave; the length was 144 mm., the breadth 102 mm., and the scapular index was 70·8. The *bones of the Shaft* had no special features, and the muscular markings were moderate.

Their length was as follows :—

Humerus, from head to tip of trochlea,	311 mm.
Radius, to tip of styloid,	249 „
„ to base „	243 „
Ulna, to tip of styloid,	265 „
„ to base „	261 „

The radio-humeral index was 80, dolichokerkic, and the forearm was long in relation to the length of the upper arm.

Shaft of Lower Limb.—In the *Femur* the extensor area on the head was slightly prolonged on to the upper part and front of the neck; the anterior intertrochanteric line was rough and broad; there was no infratrochanteric ridge.* The transverse diameter of the shaft of the femur a little below the small trochanter was 29 mm.; the antero-posterior diameter was 23 mm., and the index was 79·3; the shaft of the femur was not flattened in the upper third. The linea aspera was moderate. The inner condyl behind was prolonged a little higher than the edge of the intercondylar fossa.

The *Tibia* was somewhat retroverted at the head, the inner condylar surface was concave, the outer convexo-concave. The shaft was compressed laterally, the antero-posterior diameter was 33 mm., and the transverse 23 mm.; the index of platyknemia was 69.

The *Fibula* showed moderate muscular markings. The bones of the shaft measured as follows :—

	Right.	Left.
Femur, maximum length,	443 mm.	443 mm.
„ oblique length,	439 „	441 „
Tibia, from condylar surface to tip of malleolus,	359 „	350 „
„ „ „ astragalar surface	352 „	345 „
Fibula, maximum length,	358 „	356 „

The stature calculated from the length of the femur and tibia was probably about 5 feet 3 inches. The right tibio-femoral index was 80, the left 78, and the index was brachyknemic. The relative length of the upper arm and thigh, as expressed by the femoro-humeral index, was 70. The intermembral index was also 70.

* See my address on some Distinctive Characters of Human Structure at the Toronto meeting of the British Association, *Reports*, p. 775, *e.s.*, 1897, for an explanation of the signification of these characters.

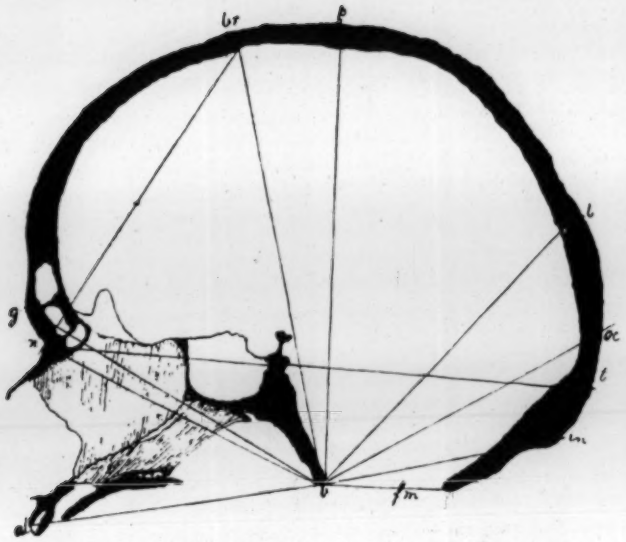

FIG. 61.—Sagittal section through skull of Tamil Sudra.
Table I., K.

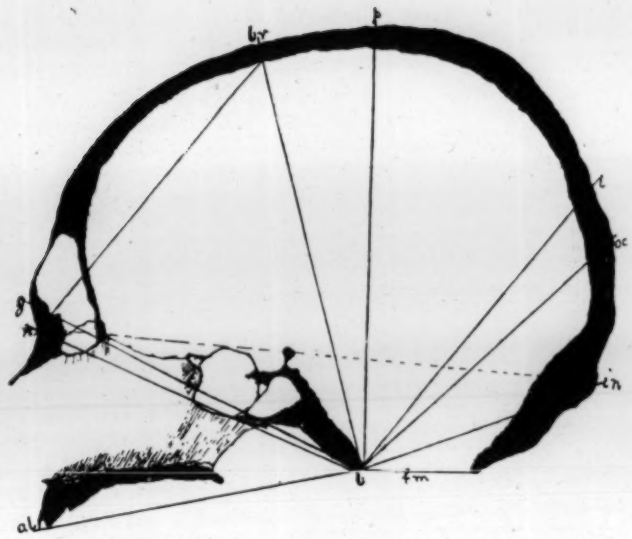

FIG. 62.—Sagittal section through skull of Thug, No. 130.
Table III.

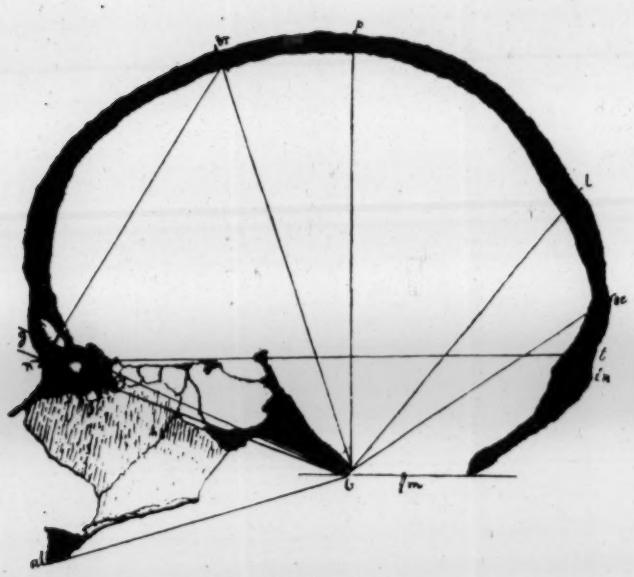

FIG. 63.—Sagittal section through skull of Thug, No. 131.
Table III.

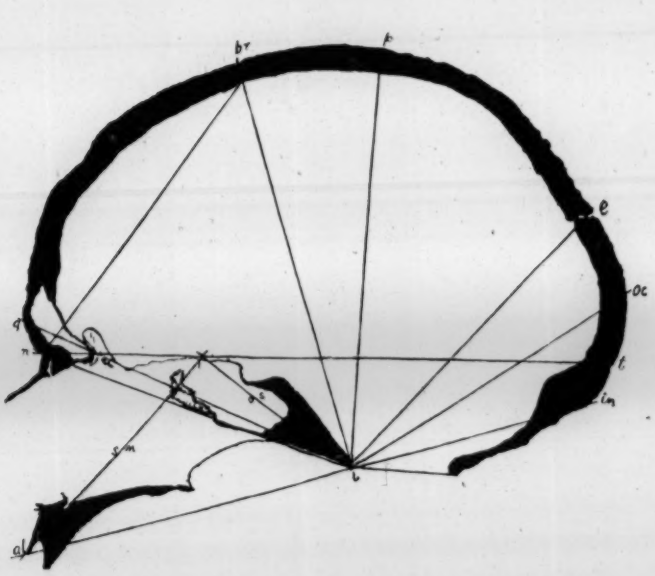

FIG. 64.—Sagittal section through skull of Veddah.
Part II., Table IX., Pl. VI. figs. 27, 28, metopic.

b.br. Basi-bregmatic radius.
b.p. ,, perpendicular radius.
b.l. ,, lambdal ,,
b.oc. ,, occipital ,,
b.in. ,, inial ,,
b.g. ,, glabellar ,,
b.n. ,, nasial radius.
b.al. ,, alveolar radius.

n.br. Nasio-bregmatic chord.
n.l. ,, tentorial plane.
f.m. Plane of foramen magnum.
o.s. Basi-occipito-sphenoid axis, 56 mm.
s.m. Spheno-maxillary line, 79 mm.
Spheno-maxillary angle, 95°.
Spheno-ethmoid angle, 144°.

EXPLANATION OF PLATES VIII.–XI.

The Plates and Figures are numbered in sequence with those of Part II. of this series of Memoirs.

The Photographs of the skulls from which the process blocks were produced were taken under my superintendence by Mr John Henderson, Assistant Keeper of the Anatomical Museum.

Plate VIII.

Fig. 37. Tamil Sudra, Trichinopoly, profile. Table I., K.
„ 38. The Same, full face.
„ 39. The Same, vertex.
„ 40. Pariah, Madras, profile. Table II., 48A.
„ 41. The Same, full face.
„ 42. The Same, vertex.

Plate IX.

Fig. 43. Badaga, Nilgiris, profile. Table II.
„ 44. The Same, full face.
„ 45. The Same, vertex.
„ 46. Lhasa, Tibet, profile. Table V.
„ 47. The Same, full face.
„ 48. The Same, vertex.

Plate X.

Fig. 49. Kham, Eastern Tibet, profile. Table V.
„ 50. The Same, full face.
„ 51. The Same, vertex.
„ 52. Chin Hills, vertex. Part I., Table I., B, Pl. 1
„ 53. Upper Burma, vertex. Part I., Table VI., Pl. III.
„ 54 Thug, profile. Table III., No. 122, Gunga Bishun.

Plate XI.

Fig. 55. Seistan, A, profile. Table V.
„ 56. The Same, full face.
„ 57. The Same, vertex.
„ 58. Seistan, C, profile. Table V.
„ 59. The Same, full face.
„ 60. The Same, vertex.

Sir William Turner on "Craniology of People of India," Part III.—Plate VIII.

Fig. 37.—Tamil Sudra.

Fig. 38.—Tamil Sudra.

Fig. 39.—Tamil Sudra.

Fig 40 —Pariah.

Fig. 41.—Pariah.

Fig. 42 —Pariah.

SIR WILLIAM TURNER on "Craniology of People of India," Part III.—PLATE IX.

FIG. 43.—Badaga.

FIG. 44.—Badaga.

FIG. 45.—Badaga.

FIG. 46.—Lhasa.

FIG. 47.—Lhasa

FIG. 48.—Lhasa.

Sir William Turner on "Craniology of People of India," Part III.—Plate X.

Fig. 49.—Kham

Fig. 50.—Kham.

Fig. 51.—Kham

Fig. 52.—Chin, B.

Fig. 53.—Upper Burma.

Fig. 54.—Thug.

SIR WILLIAM TURNER on "Craniology of People of India," Part III.—PLATE XI.

FIG. 55.—Seistan, A.

FIG. 56.—Seistan, A.

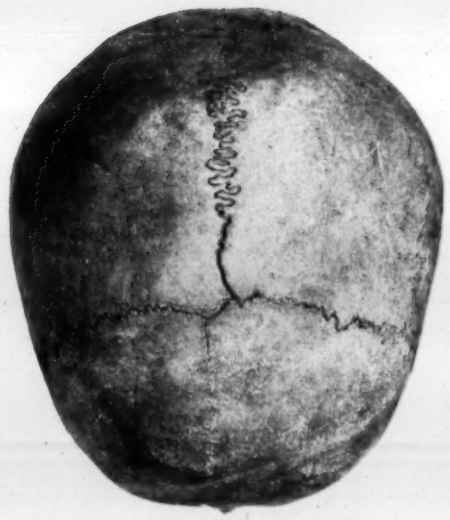

FIG. 57.—Seistan, A.

FIG. 58.—Seistan, C.

FIG. 59.—Seistan, C.

FIG. 60.—Seistan, C.

XI.—A Pfaffian Identity, and related Vanishing Aggregates of Determinant Minors. By Thomas Muir, LL.D.

(MS. received February 26, 1906. Issued separately August 16, 1906.)

(1) An essential part of PFAFF's method of solving an ordinary differential equation in $2m$ variables consists in obtaining what he calls his auxiliary equations. If the given equation be

$$A\partial a + B\partial b + C\partial c + E\partial e + F\partial f + G\partial g = 0$$

the auxiliary equations are

$$\begin{aligned} 0 = & \frac{\partial a}{(CBE)(CFG) - (CBF)(CEG) + (CBG)(CEF)} \\ & + \frac{\partial b}{(CAE)(CFG) - (CAF)(CEG) + (CAG)(CEF)}, \\ = & \quad \ldots\ldots\ldots\

Taking the case where the given equation has six variables, and where the first form of one of the denominators pertaining to the auxiliary equations is

$$(BCE)(BFG) \;-\; (BCF)(BEG) \;+\; (BCG)(BEF),$$

we find that the second form is

$$\begin{aligned}
&B\left[\begin{array}{l} C^{v}E^{vi} - C^{iv}F^{vi} + C^{iv}G^{v} - E^{v}C^{vi} + E^{iii}F^{vi} - E^{iii}G^{v} \\ + F^{iv}C^{vi} - F^{iii}E^{vi} + F^{iii}G^{iv} - G^{iv}C^{v} + G^{iii}E^{v} - G^{iii}F^{iv} \end{array}\right] \\
&-C\left[\begin{array}{l} B^{v}E^{vi} - B^{iv}F^{vi} + \cdots\cdots\cdots \\ + F^{iv}B^{vi} - F^{ii}E^{vi} + \cdots\cdots\cdots \end{array}\right] \\
&+E\left[\begin{array}{l} B^{v}C^{vi} - B^{iii}F^{vi} + \cdots\cdots\cdots \\ + F^{iii}B^{vi} - F^{ii}C^{vi} + \cdots\cdots\cdots \end{array}\right] \\
&-F\left[\begin{array}{l} B^{iv}C^{vi} - B^{iii}E^{vi} + \cdots\cdots\cdots \\ + E^{iii}B^{vi} - E^{ii}C^{vi} + \cdots\cdots\cdots \end{array}\right] \\
&+G\left[\begin{array}{l} B^{iv}C^{v} - B^{iii}E^{v} + \cdots\cdots\cdots \\ + E^{iii}B^{v} - E^{ii}C^{v} + \cdots\cdots\cdots \end{array}\right]
\end{aligned}$$

where $B^{i}, B^{ii}, \ldots\ldots, C^{i}, \ldots\ldots, G^{vi}$ stand for

$$\frac{\partial B}{\partial a}, \frac{\partial B}{\partial b}, \ldots\ldots, \frac{\partial C}{\partial a}, \ldots\ldots, \frac{\partial G}{\partial g}$$

respectively. The problem is thus suggested of justifying the use of one of these for the other; and with the setting of this problem the present paper originated.

(2) By using the notation of the second form in writing the first form the latter becomes

$$\begin{aligned}
&\{BC^{iv} - BE^{iii} - CB^{iv} + CE^{ii} + EB^{iii} - EC^{ii}\}\{BF^{vi} - BG^{v} - FB^{vi} + FG^{ii} + GB^{v} - GF^{ii}\} \\
&-\{BC^{v} - BF^{iii} - CB^{v} + CF^{ii} + FB^{iii} - FC^{ii}\}\{BE^{vi} - BG^{iv} - EB^{vi} + EG^{ii} + GB^{iv} - GE^{ii}\} \\
&+\{BC^{vi} - BG^{iii} - CB^{vi} + CG^{ii} + GB^{iii} - GC^{ii}\}\{BE^{v} - BF^{iv} - EB^{v} + EF^{ii} + FB^{iv} - FE^{ii}\};
\end{aligned}$$

and it is readily seen that, whatever the relation between the two forms may be, it is not dependent on the meaning here given to the indices, but that in fact it is a relation connecting the elements of the five-by-six array

$$\begin{array}{cccccc}
B & . & B_3 & B_4 & B_5 & B_6 \\
C & C_2 & . & C_4 & C_5 & C_6 \\
E & E_2 & E_3 & . & E_5 & E_6 \\
F & F_2 & F_3 & F_4 & . & F_6 \\
G & G_2 & G_3 & G_4 & G_5 & . \;\; .
\end{array}$$

It is such relations, therefore, that have to be investigated. Before doing so, however, the particular relation suggested by PFAFF may be established separately. Changing the first form into

$$\begin{aligned}
&(|BC_4| + |CE_2| + |EB_3|)(|BF_6| + |FG_2| + |GB_5|) \\
&-(|BC_5| + |CF_2| + |FB_3|)(|BE_6| + |EG_2| + |GB_4|) \\
&+(|BC_6| + |CG_2| + |GB_3|)(|BE_5| + |EF_2| + |FB_4|)
\end{aligned}$$

and performing the multiplications indicated, we have an expression of twenty-seven

terms $|BC_4| \cdot |BF_6| + \cdots$. Those twenty-seven terms may be grouped into five sets of three, on which the identity *

$$\begin{vmatrix} |a_1b_3| & |a_1c_3| & |a_1d_3| \\ & |b_1c_2| & |b_1d_2| \\ & & |c_1d_2| \end{vmatrix} = a_1 |b_2c_3d_4|$$

may be used, and six sets of two, on which the identity

$$|b_2c_3| \cdot |c_3d_4| - |b_3c_4| \cdot |c_2d_3| = c_3 |b_2c_3d_4|$$

may be used; and as one of the three-line determinants thus obtained vanishes, and the others all have the cofactor B, the result is

$$-B\begin{bmatrix} |BC_5E_6| - |BC_4F_6| + |BC_4G_5| - |BE_3F_6| + |BE_3G_5| - |BF_3G_4| \\ + |CE_2F_6| - |CE_2G_5| + |CF_2G_4| - |EF_2G_3| \end{bmatrix}.$$

When the sixty terms which form the final expansion of the cofactor of $-B$ here are regrouped into five sets of twelve, so as to give the cofactors of B, C, E, F, G, PFAFF's second form of denominator is reached.

(3) The determinant aggregate

$$|a_3b_4| - |a_2c_4| + |b_1c_4|,$$

in which the sign of each determinant is dependent on the number of inverted pairs in the row of integers consisting of the row-numbers of the determinant followed immediately by the column-numbers, has been found † to be conveniently representable by

$$\sum \begin{vmatrix} 1 & 2 \\ 3 & 4 \end{vmatrix},$$

* It does not seem to have been noted before that

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ . & c_2 & c_3 & c_4 \\ . & d_2 & d_3 & d_4 \end{vmatrix} = \begin{vmatrix} |a_1b_2| & |a_1b_3| & |a_1b_4| \\ & |c_2d_3| & |c_2d_4| \\ & & |c_3d_4| \end{vmatrix}$$

and that therefore

$$|a_1b_2c_3d_4| = \begin{vmatrix} |a_1b_2| & |a_1b_3| & |a_1b_4| \\ & |c_2d_3| & |c_2d_4| \\ & & |c_2d_4| \end{vmatrix} + \begin{vmatrix} |c_1d_2| & |c_1d_3| & |c_1d_4| \\ & |a_2b_3| & |a_2b_4| \\ & & |a_3b_4| \end{vmatrix};$$

similarly, that

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & b_2 & b_3 & b_4 & b_5 & b_6 \\ . & c_2 & c_3 & c_4 & c_5 & c_6 \\ . & d_2 & d_3 & d_4 & d_5 & d_6 \\ . & e_2 & e_3 & e_4 & e_5 & e_6 \\ . & f_2 & f_3 & f_4 & f_5 & f_6 \end{vmatrix} = \begin{vmatrix} |a_1b_2| & |a_1b_3| & |a_1b_4| & |a_1b_5| & |a_1b_6| \\ & |c_2d_3| & |c_2d_4| & |c_2d_5| & |c_2d_6| \\ & & |c_3d_4| & |c_3d_5| & |c_3d_6| \\ & & & |e_4f_5| & |e_4f_6| \\ & & & & |e_5f_6| \end{vmatrix} + \begin{vmatrix} |a_1b_2| & |a_1b_3| & |a_1b_4| & |a_1b_5| & |a_1b_6| \\ & |e_2f_3| & |e_2f_4| & |e_2f_5| & |e_2f_6| \\ & & |e_3f_4| & |e_3f_5| & |e_3f_6| \\ & & & |c_4d_5| & |c_4d_6| \\ & & & & |c_5d_6| \end{vmatrix},$$

and therefore that

$$\begin{aligned} |a_1b_2c_3d_4e_5f_6| = & \begin{vmatrix} |a_1b_2| & |c_2d_3| & |c_3d_4| & |e_4f_5| & |e_5f_6| \end{vmatrix} + \begin{vmatrix} |a_1b_2| & |e_2f_3| & |e_3f_4| & |c_4d_5| & |c_5d_6| \end{vmatrix} \\ & + \begin{vmatrix} |c_1d_2| & |a_2b_3| & |a_3b_4| & |e_4f_5| & |e_5f_6| \end{vmatrix} + \begin{vmatrix} |c_1d_2| & |e_2f_3| & |e_3f_4| & |a_4b_5| & |a_5b_6| \end{vmatrix} \\ & + \begin{vmatrix} |e_1f_2| & |a_2b_3| & |a_3b_4| & |c_4d_5| & |c_5d_6| \end{vmatrix} + \begin{vmatrix} |e_1f_2| & |c_2d_3| & |c_3d_4| & |a_4b_5| & |a_5b_6| \end{vmatrix}; \end{aligned}$$

and generally that *a determinant of order* 2m *is expressible as a sum of* m! *Pfaffians*. When the Pfaffians are expanded the terms obtained are those given by LAPLACE's expansion-theorem.

† *Philos. Magazine* (1884), xviii. pp. 416–427; (1902) (6), iii. pp. 411–416.

where the dot below the 4 is used to indicate that, while the other integers vary their position, the 4 remains unchanged throughout. It has now to be noted that the constituent determinants of the aggregate are those of the three-by-four array

$$\begin{matrix} . & a_2 & a_3 & a_4 \\ b_1 & . & b_3 & b_4 \\ c_1 & c_2 & . & c_4 \end{matrix}$$

which contain no zero elements: also that the said aggregate is expressible as the difference of two Pfaffians, namely,

$$- \begin{vmatrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{vmatrix} + \begin{vmatrix} b_1 & c_1 & a_4 \\ & & c_2 & b_4 \\ & & & c_4 \end{vmatrix},$$

where the first of the two is apparent in the original array, and the second is got from the first by substituting for a_2, a_3, b_3 the elements conjugate to them in the said array.

When $|a_1b_2c_3|$ is axisymmetric the aggregate vanishes,* and when $|a_1b_2c_3|$ is skew the aggregate becomes†

$$-2 \begin{vmatrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{vmatrix}$$

—facts that are most readily verified by considering the bi-Pfaffian form.

The two-line minors of the determinant

$$\begin{vmatrix} . & a_2 & a_3 & a_4 \\ b_1 & . & b_3 & b_4 \\ c_1 & c_2 & . & c_4 \\ d_1 & d_2 & d_3 & . \end{vmatrix}$$

which have no zero elements are $C_{4,2}$ in number, namely,

$$\begin{matrix} |\, a_3b_4 \,| & -|\, a_2c_4 \,| & |\, b_1c_4 \,| \\ & |\, a_2d_3 \,| & -|\, b_1d_3 \,| \\ & & |\, c_1d_2 \,|. \end{matrix}$$

The sum of the elements of the r^{th} frame-line of this Pfaffian matrix is the aggregate derivable from the r^{th} set of three rows of the determinant, and the sum of the remaining elements of the matrix is the aggregate derivable from the r^{th} set of three columns. The sum of the aggregates derivable from the rows is thus the same as the sum of the aggregates derivable from the columns, namely, $2\sum \left| \begin{smallmatrix} 1 & 2 \\ 3 & 4 \end{smallmatrix} \right|$.

(4) Similarly, the aggregate

$$|\, a_4b_5c_6 \,| - |\, a_3b_5d_6 \,| + |\, a_2c_5d_6 \,| - |\, b_1c_5d_6 \,|,$$

which is representable by

$$\sum \left| \begin{smallmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right|$$

* *Sitzungsb. d. k. Akad. d. Wiss.* (*Berlin*) (1882), pp. 821–824.

† *Proceedings Roy. Soc. Edinburgh* (1900), xxiii. pp. 142–154.

has for its constituent determinants the three-line minors of the four-by-six array

$$\begin{matrix} . & a_2 & a_3 & a_4 & a_5 & a_6 \\ b_1 & . & b_3 & b_4 & b_5 & b_6 \\ c_1 & c_2 & . & c_4 & c_5 & c_6 \\ d_1 & d_2 & d_3 & . & d_5 & d_6 \end{matrix}$$

which have no zero elements, and is equal to

$$-\begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3 & b_4 & b_5 & b_6 \\ & & c_4 & c_5 & c_6 \\ & & & d_5 & d_6 \\ & & & & . \end{vmatrix} + \begin{vmatrix} b_1 & c_1 & d_1 & a_5 & a_6 \\ & & c_2 & d_2 & b_5 & b_6 \\ & & & d_3 & c_5 & c_6 \\ & & & & d_5 & d_6 \\ & & & & & . \end{vmatrix},$$

a form which shows that it vanishes when $|a_1b_2c_3d_4|$ is axisymmetric, and becomes

$$-2\begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3 & b_4 & b_5 & b_6 \\ & & c_4 & c_5 & c_6 \\ & & & d_5 & d_6 \\ & & & & . \end{vmatrix}$$

when $|a_1b_2c_3d_4|$ is skew.

The three-line minors of $|a_1b_2c_3d_4e_5f_6|$ which contain none of the diagonal elements are $6\cdot5\cdot4/3\cdot2\cdot1$ in number, namely, one for every set of three rows: and the sum of the aggregates derivable from the rows is the same as the corresponding sum derivable from the columns, namely, $3\sum\begin{vmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}$.

(5) The general theorem which is at the basis of all such results is—*If the elements on one side of the principal diagonal of a zero-axial determinant of the* $2m^{th}$ *order be removed to the other side, each being attached to its conjugate by the sign* $-$, *the Pfaffian of the matrix so formed is equal to the aggregate of the* m*-line minors of the original determinant which contain no zero elements.* The same stated in symbols and without any reference to an originating zero-axial determinant is

$$\left|\begin{matrix} 1_2-2_1, & 2_3-3_2, & 3_4-4_3, & \dots, & (m-1)_m-(m)_{m-1} \end{matrix}\right| = \sum\begin{vmatrix} 1, & 2, & 3, & \dots, & m \\ m+1, & m+2, & m+3, & \dots, & 2m \end{vmatrix}.$$

To establish this, let us begin with the case where $m=2$. Evidently we then have the given Pfaffian

$$\begin{vmatrix} a_2-b_1 & a_3-c_1 & a_4-d_1 \\ & b_3-c_2 & b_4-d_2 \\ & & c_4-d_3 \end{vmatrix} = \begin{vmatrix} a_2 & a_3 & a_4 \\ & b_3-c_2 & b_4-d_2 \\ & & c_4-d_3 \end{vmatrix} - \begin{vmatrix} b_1 & c_1 & d_1 \\ & b_3-c_2 & b_4-d_2 \\ & & c_4-d_3 \end{vmatrix},$$

and therefore, from § 3, equal to

$$\{|a_2c_4| - |a_3b_4| - |a_2d_3|\} - \{|b_1c_4| - |b_3d_1| \quad |c_1d_2|\}$$

$$= -\sum\begin{vmatrix} 1 & 2 \\ 3 & 4 \end{vmatrix} + \sum\begin{vmatrix} 3 & 4 \\ 1 & 2 \end{vmatrix}$$

$$= -\sum\begin{vmatrix} 1 & 2 \\ 3 & 4 \end{vmatrix}.$$

Taking next the case where $m = 3$, we express the Pfaffian

$$\begin{vmatrix} a_2-b_1 & a_3-c_1 & a_4-d_1 & a_5-e_1 & a_6-f_1 \\ & b_3-c_2 & b_4-d_2 & b_5-e_2 & b_6-f_2 \\ & & c_4-d_3 & c_5-e_3 & c_6-f_3 \\ & & & d_5-e_4 & d_6-f_4 \\ & & & & e_6-f_5 \end{vmatrix}$$

in terms of the elements of the first frame-line and their complementary minors, thus obtaining

$$(a_2-b_1)\cdot\begin{vmatrix} c_4-d_3 & c_5-e_3 & c_6-f_3 \\ d_5-e_4 & d_6-f_4 \\ e_5-f_5 \end{vmatrix} - (a_3-c_1)\cdot\begin{vmatrix} b_4-d_2 & b_5-e_2 & b_6-f_2 \\ & d_5-e_5 & d_6-f_4 \\ & & e_6-f_5 \end{vmatrix} + \cdots\cdots;$$

then, using the previous case, we change this into

$$-(a_2-b_1)\cdot\Sigma\begin{vmatrix} 3 & 4 \\ 5 & 6 \end{vmatrix} + (a_3-c_1)\cdot\Sigma\begin{vmatrix} 2 & 4 \\ 5 & 6 \end{vmatrix} - \cdots\cdots;$$

thirdly, as before, we separate the portion containing the a's from that independent of the a's, and find * the former, namely $-a_2\Sigma\begin{vmatrix} 3 & 4 \\ 5 & 6 \end{vmatrix} + a_3\Sigma\begin{vmatrix} 2 & 4 \\ 5 & 6 \end{vmatrix} - \ldots$ equal to $-\Sigma\begin{vmatrix} 1 & 3 & 4 \\ 2 & 5 & 6 \end{vmatrix}$, and the latter, being the portion involving the suffix 1, equal to $+\Sigma\begin{vmatrix} 2 & 3 & 4 \\ 1 & 5 & 6 \end{vmatrix}$; and finally we combine those portions and obtain

$$-\Sigma\begin{vmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}.$$

The case where $m = 4$ follows in the same way from the case where $m = 3$, and so on generally.

(6) The representation of the determinant aggregate $\Sigma\begin{vmatrix} 1 & 2 & \ldots & m \\ m+1, & m+2, & \ldots & 2m \end{vmatrix}$ by a single Pfaffian puts the whole subject of the vanishing of such aggregates on an entirely new footing; and, as may be guessed from the last step of the proof, the advantage extends to all the dotted or restricted aggregates as well, for every one of those can be represented in the same manner.

By way of illustration let us examine the aggregate

$$\Sigma\begin{vmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}$$

* To prove that

$$a_2\Sigma\begin{vmatrix} 3 & 4 \\ 5 & 6 \end{vmatrix} - a_3\Sigma\begin{vmatrix} 2 & 4 \\ 5 & 6 \end{vmatrix} + a_4\Sigma\begin{vmatrix} 2 & 3 \\ 5 & 6 \end{vmatrix} - a_5\Sigma\begin{vmatrix} 2 & 3 \\ 4 & 6 \end{vmatrix} + a_6\Sigma\begin{vmatrix} 2 & 3 \\ 4 & 5 \end{vmatrix} = \Sigma\begin{vmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}$$

it suffices to show that the ten three-line determinants on the right are all represented on the left, and that nothing else than such representatives are there to be found. Taking, for example, the fourth three-line determinant, $-\begin{vmatrix} 1 & 2 & 6 \\ 3 & 4 & 5 \end{vmatrix}$, we partition it into $-a_3\begin{vmatrix} 2 & 6 \\ 4 & 5 \end{vmatrix}$, $a_4\begin{vmatrix} 2 & 6 \\ 3 & 5 \end{vmatrix}$, $-a_5\begin{vmatrix} 2 & 6 \\ 3 & 4 \end{vmatrix}$, the first of which appears on the left in $-a_3\Sigma\begin{vmatrix} 2 & 4 \\ 5 & 6 \end{vmatrix}$, the second in $a_4\Sigma\begin{vmatrix} 2 & 3 \\ 5 & 6 \end{vmatrix}$, and the third in $-a_5\Sigma\begin{vmatrix} 2 & 3 \\ 4 & 6 \end{vmatrix}$. The number of such parts on the left being 5×4, and on the right 10×3, the other requisite is provided for.

and the related dotted aggregates

$$\Sigma\left|\begin{smallmatrix}1&2&3\\4&5&6\end{smallmatrix}\right|,\ \Sigma\left|\begin{smallmatrix}1&2&3\\4&5&6\end{smallmatrix}\right|,\ \Sigma\left|\begin{smallmatrix}\dot1&\dot2&3\\4&5&6\end{smallmatrix}\right|,\ \Sigma\left|\begin{smallmatrix}\dot1&2&3\\\dot4&5&6\end{smallmatrix}\right|,\ \ldots\ldots$$

The Pfaffian form of the first of these being

$$-\left|\begin{matrix} a_2-b_1 & a_3-c_1 & a_4-d_1 & a_5-e_1 & a_6-f_1\\ & b_3-c_2 & b_4-d_2 & b_5-e_2 & b_6-f_2\\ & & c_4-d_3 & c_5-e_3 & c_6-f_3\\ & & & d_5-e_4 & d_6-f_4\\ & & & & e_6-f_5 \end{matrix}\right|,$$

it is at once evident that it will vanish if each element of any one of its principal minors vanishes.* If we take, for example, the principal minor which is the cofactor of a_2-b_1, namely,

$$\left|\begin{matrix} c_4-d_3 & c_5-e_3 & c_6-f_3\\ & d_5-e_4 & d_6-f_4\\ & & e_6-f_5 \end{matrix}\right|,$$

the condition then is

$$c_4,\ c_5,\ c_6,\ d_5,\ d_6,\ e_6 \ = \ d_3,\ e_3,\ f_3,\ e_4,\ f_4,\ f_5\,;$$

in other words, that $|c_3d_4e_5f_6|$ shall be axisymmetric. There being fifteen principal minors of the Pfaffian, and each one having corresponding to it a four-line coaxial minor of the determinant $|a_1b_2c_3d_4e_5f_6|$, the result we thus reach is—*The determinant aggregate* $\Sigma\left|\begin{smallmatrix}1&2&3\\4&5&6\end{smallmatrix}\right|$ *vanishes when any one of the four-line coaxial minors of* $|a_1b_2c_3d_4e_5f_6|$ *is axisymmetric.*

The next aggregate, $\Sigma\left|\begin{smallmatrix}\dot1&2&3\\4&5&6\end{smallmatrix}\right|$, need not detain us, as we have already seen in § 5 that it is equal to

$$-\left|\begin{matrix} a_2 & a_3 & a_4 & a_5 & a_6\\ & b_3-c_2 & b_4-d_2 & b_5-e_2 & b_6-f_2\\ & & c_4-d_3 & c_5-e_3 & c_6-f_3\\ & & & d_5-e_4 & d_6-f_4\\ & & & & e_6-f_5 \end{matrix}\right|,$$

the dot over the 1 being equivalent to an injunction to strike out from the Pfaffian for $\Sigma\left|\begin{smallmatrix}1&2&3\\4&5&6\end{smallmatrix}\right|$ all the elements having 1 for a suffix. By mere inspection it is evident that the conditions for evanescence are narrower than in the case of $\Sigma\left|\begin{smallmatrix}1&2&3\\4&5&6\end{smallmatrix}\right|$, the result now being—*The determinant aggregate* $\Sigma\left|\begin{smallmatrix}\dot1&2&3\\4&5&6\end{smallmatrix}\right|$ *vanishes when any one of the four-line coaxial minors of* $|b_2c_3d_4e_5f_6|$ *is axisymmetric.*

When the single dotted line-number is below, that is to say, is a *column* number,

* It would, of course, also vanish if each element in any one of its frame-lines were to vanish: that is to say, if equivalence of conjugates were confined to any one row of the determinant $|a_1b_2c_3d_4e_5f_6|$,—for example, if

$$a_2, a_3, a_4, a_5, a_6 \ = \ b_1, c_1, d_1, e_1, f_1\,.$$

This suggests a new avenue of investigation, and an avenue of special interest, because the number of conditional equations requisite for the evanescence of the aggregate may as here be less. Like previous writers, however, we are confining ourselves to vanishing produced by axisymmetry of a whole determinant.

the dot beneath it indicates that it is permanently appropriated as such, and that therefore no element with 1 as a *row*-number appears in the aggregate. Thus, as we have seen in § 5, $\sum \left| \begin{smallmatrix} 2 & 3 & 4 \\ \dot{1} & 5 & 6 \end{smallmatrix} \right|$ is equal to

$$\begin{vmatrix} -b_1 & -c_1 & -d_1 & -e_1 & -f_1 \\ & b_3-c_2 & b_4-d_2 & b_5-e_2 & b_6-f_2 \\ & & c_4-d_3 & c_5-e_3 & c_6-f_3 \\ & & & d_5-e_4 & d_6-f_4 \\ & & & & e_6-f_5 \end{vmatrix},$$

which shows that $\sum \left| \begin{smallmatrix} 2 & 3 & 4 \\ \dot{1} & 5 & 6 \end{smallmatrix} \right|$ vanishes under the same circumstances * as $\sum \left| \begin{smallmatrix} \dot{1} & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right|$.

The fourth aggregate, $\sum \left| \begin{smallmatrix} \dot{1} & \dot{2} & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right|$, has for its equivalent the Pfaffian obtained from $\| a_2-b_1,\ b_3-c_2, \ldots, e_6-f_5 |$ by deleting all the elements having either the suffix 1 or the suffix 2, and therefore is

$$-\begin{vmatrix} . & a_3 & a_4 & a_5 & a_6 \\ & b_3 & b_4 & b_5 & b_6 \\ & & c_4-d_3 & c_5-e_3 & c_6-f_3 \\ & & & d_5-e_4 & d_6-f_4 \\ & & & & e_6-f_5 \end{vmatrix}.$$

It consequently vanishes when $| c_3 d_4 e_5 f_6 |$ is axisymmetric.† It is known as a Kronecker aggregate, being one of the aggregates which, according to Kronecker, all vanish when $| a_1 b_2 c_3 d_4 e_5 f_6 |$ is axisymmetric.

To obtain the Pfaffian equivalent of the fifth aggregate, $\sum \left| \begin{smallmatrix} \dot{1} & 2 & 3 \\ \dot{4} & 5 & 6 \end{smallmatrix} \right|$, we in like manner strike out from $\| a_2-b_1,\ b_3-c_2, \ldots, e_6-f_5 |$ all the elements having the column-number 1 (here a suffix) and all the elements with the row-number 4 (here a d), the outcome being

$$-\begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3-c_2 & b_4 & b_5-e_2 & b_6-f_2 \\ & & c_4 & c_5-e_3 & c_6-f_3 \\ & & & -e_4 & -f_4 \\ & & & & e_6-f_5 \end{vmatrix}.$$

This will vanish if each of the elements of the complementary minor of a_4, namely, the minor

$$\begin{vmatrix} b_3-c_2 & b_5-e_2 & b_6-f_2 \\ & c_5-e_3 & c_6-f_3 \\ & & e_6-f_5 \end{vmatrix},$$

vanishes: in other words, if $| b_2 c_3 e_5 f_6 |$ be axisymmetric.

* Observe that the result deducible regarding the evanescence of $\sum \left| \begin{smallmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right|$ from making use of the fact that

$$\sum \left| \begin{smallmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right| = \sum \left| \begin{smallmatrix} \dot{1} & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right| - \sum \left| \begin{smallmatrix} 2 & 3 & 4 \\ \dot{1} & 5 & 6 \end{smallmatrix} \right|$$

is less extensive than that before obtained. In this connection it is well also to note that if three selected four-line coaxial minors of $| a_1 b_2 c_3 d_4 e_5 f_6 |$ be axisymmetric, all the twelve others must be axisymmetric; for example, the axisymmetry of $| a_1 b_2 c_3 d_4 \ , | a_1 b_2 e_5 f_6 |$, $| c_3 d_4 e_5 f_6 |$ implies the axisymmetry of $| a_1 b_2 c_3 d_4 e_5 f_6 |$.

† See *Proceedings Roy. Soc. Edinburgh*, xxiii., p. 147, § 5.

When three or more of the line-numbers of $\Sigma \left| \begin{smallmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{smallmatrix} \right|$ are dotted, it is readily seen that the aggregate so denoted cannot vanish by the imposition of axisymmetry, so that all the possible cases have been considered. Looking back over them, we observe that in every case evanescence of the aggregate is dependent on the axisymmetry of a four-line determinant, and that this determinant is a coaxial minor of the determinant whose row and column numbers are the undotted line-numbers of the aggregate. We thus have the following interesting generalisation—*Any aggregate of three-line determinants will vanish if a four-line coaxial minor of the determinant whose row and column numbers are the undotted line-numbers of the aggregate be axisymmetric*; and it is not hard to see that the theorem is not confined to three-line aggregates only.

(7) Let us now consider the Pfaffians which differ from those of §§ 5, 6 in having for elements not $a_2, a_3, \ldots$ but the complementary minors of $a_2, a_3, \ldots$ in $\| a_2 b_3 c_4 d_5 e_6 |$: and first let us take a Pfaffian of the second order, say

$$\begin{vmatrix} C_4 - C_4' & C_5 - C_5' & C_6 - C_6' \\ & D_5 - D_5' & D_6 - D_6' \\ & & E_6 - E_6' \end{vmatrix}$$

where $C_4, C_5, \ldots$ are the complementary minors of $c_4, c_5, \ldots$, and C_4' is what C_4 becomes when each element outside the first line of C_4 is changed into its conjugate; for example

$$E_6 - E_6' = \begin{vmatrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{vmatrix} - \begin{vmatrix} a_2 & a_3 & a_4 \\ & & c_2 & d_2 \\ & & & d_3 \end{vmatrix}.$$

Expressing each of the elements of the given Pfaffian in terms of the a's and their cofactors, we find the Pfaffian equal to

$$\begin{aligned} &\{a_2(e_6 - f_5) - a_5(b_6 - f_2) + a_6(b_5 - e_2)\} \cdot \{a_2(c_4 - d_3) - a_3(b_4 - d_2) + a_4(b_3 - c_2)\} \\ - &\{a_2(d_6 - f_4) - a_4(b_6 - f_2) + a_6(b_4 - d_2)\} \cdot \{a_2(c_5 - e_3) - a_3(b_5 - e_2) + a_5(b_3 - c_2)\} \\ + &\{a_2(d_5 - e_4) - a_4(b_5 - e_2) + a_5(b_4 - d_2)\} \cdot \{a_2(c_6 - f_3) - a_3(b_6 - f_2) + a_6(b_3 - c_2)\}. \end{aligned}$$

In the expansion of this there are evidently terms in a_2a_2, a_2a_3, a_2a_4, a_2a_5, a_2a_6 and terms independent of a_2. The cofactor of a_2a_2 is

$$\begin{vmatrix} e_6 - f_5 & d_6 - f_4 & c_6 - f_3 \\ & d_5 - e_4 & c_5 - e_3 \\ & & c_4 - d_3 \end{vmatrix},$$

which from § 5 we know to be equal to $-\Sigma \left| \begin{smallmatrix} 3 & 4 \\ 5 & 6 \end{smallmatrix} \right|$; similarly, the cofactors of a_2a_3, a_2a_4, a_2a_5, a_2a_6 are found to be

$$\Sigma \left| \begin{smallmatrix} 2 & 4 \\ 5 & 6 \end{smallmatrix} \right|, \quad -\Sigma \left| \begin{smallmatrix} 2 & 3 \\ 5 & 6 \end{smallmatrix} \right|, \quad \Sigma \left| \begin{smallmatrix} 2 & 3 \\ 4 & 6 \end{smallmatrix} \right|, \quad \Sigma \left| \begin{smallmatrix} 2 & 3 \\ 4 & 5 \end{smallmatrix} \right|;$$

and, manifestly, the cofactors of $a_3a_4, a_3a_5, \ldots, a_5a_6$ all vanish. The given compound Pfaffian is thus equal to

$$a_2 \left\{ -a_2 \Sigma \left| \begin{smallmatrix} 3 & 4 \\ 5 & 6 \end{smallmatrix} \right| + a_3 \Sigma \left| \begin{smallmatrix} 2 & 4 \\ 5 & 6 \end{smallmatrix} \right| - a_4 \Sigma \left| \begin{smallmatrix} 2 & 3 \\ 5 & 6 \end{smallmatrix} \right| + a_5 \Sigma \left| \begin{smallmatrix} 2 & 3 \\ 4 & 6 \end{smallmatrix} \right| - a_6 \Sigma \left| \begin{smallmatrix} 2 & 3 \\ 4 & 5 \end{smallmatrix} \right| \right\}$$

and therefore (§ 5) is equal to

$$-a_2\Sigma\begin{vmatrix} \dot{1} & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}.$$

(8) The result of the preceding paragraph, which may also be written

$$\begin{vmatrix} \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 4 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 5 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 6 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 5 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 6 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 5 & 6 \end{vmatrix} \end{vmatrix} = -\frac{1}{2}\cdot\Sigma\begin{vmatrix} \dot{1} & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix},$$

is the identity which accounts for the alternative forms of the denominators in Pfaff's auxiliary equations. It is also interesting as giving an expression for $\Sigma\begin{vmatrix} \dot{1} & 2 & 3 \\ 4 & 5 & 6 \end{vmatrix}$ in terms of similar aggregates of lower order. Further, by comparison of it with the second result of § 6 we deduce the curious identity

$$\begin{vmatrix} \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 4 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 5 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 6 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 5 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 6 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 5 & 6 \end{vmatrix} \end{vmatrix} = a_2\begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3-c_2 & b_4-d_2 & b_5-e_2 & b_6-f_2 \\ & & c_4-d_3 & c_5-e_3 & c_6-f_3 \\ & & & d_5-e_4 & d_6-f_4 \\ & & & & e_6-f_5 \end{vmatrix}.$$

(9) As for the Pfaffian corresponding to the full adjugate of $\|a_2b_3c_4d_5e_6\|$, namely

$$\begin{vmatrix} A_2-A_2' & A_3-A_3' & A_4-A_4' & A_5-A_5' & A_6-A_6' \\ & B_3-B_3' & B_4-B_4' & B_5-B_5' & B_6-B_6' \\ & & \cdot\ \cdot\ \cdot & \cdot\ \cdot\ \cdot & \cdot\ \cdot\ \cdot \\ & & & & E_6-E_6' \end{vmatrix}$$

or

$$\begin{vmatrix} \Sigma\begin{vmatrix} \dot{3} & 4 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{2} & 4 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{2} & 3 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{2} & 3 \\ 4 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{2} & 3 \\ 4 & 5 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 4 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 3 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 3 \\ 4 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 3 \\ 4 & 5 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 5 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 4 & 5 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 6 \end{vmatrix} & \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 5 \end{vmatrix} \\ \Sigma\begin{vmatrix} \dot{1} & 2 \\ 3 & 4 \end{vmatrix} \end{vmatrix},$$

it is of course equal to

$$(A_2-A_2')\begin{vmatrix} C_4-C_4' & C_5-C_5' & C_6-C_6' \\ & D_5-D_5' & D_6'-D_6' \\ & & E_6-E_6' \end{vmatrix} - (A_3-A_3')\begin{vmatrix} B_4-B_4 & B_5-B_5' & B_6-B_6' \\ & D_5-D_5' & D_6-D_6' \\ & & E_6-E_6' \end{vmatrix} + \cdots\cdots$$

and therefore by the main result of § 7

$$= -(A_2 - A_2')\cdot a_2 \sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| + (A_3 - A_3')\cdot a_3 \ldots \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| - \ldots\ldots,$$

$$= \sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| \cdot \left\{ -(a_2 A_2 - a_3 A_3 + \cdots) + (a_2 A_2' - a_3 A_3' + \cdots) \right\},$$

$$= \sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| \cdot \left\{ - \begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3 & b_4 & b_5 & b_6 \\ & & c_4 & c_5 & c_6 \\ & & & d_5 & d_6 \\ & & & & e_6 \end{vmatrix} + \begin{vmatrix} a_2 & a_3 & a_4 & a_5 & a_6 \\ & b_3 & b_4 & b_5 & b_6 \\ & & d_3 & e_3 & f_3 \\ & & & e_4 & f_4 \\ & & & & f_5 \end{vmatrix} \right\}.$$

(10) In dealing with the identities of §§ 5, 6, the only special case considered was that which arises from making conjugate elements identical: the results, however, are equally interesting when conjugate elements are made to differ only in sign. Doing this, we find that

$$\sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| = -8\,|a_2 b_3 c_4 d_5 e_6| \quad \text{when} \quad |a_1 b_2 c_3 d_4 e_5 f_6| \text{ is skew:}$$

$$\sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| = -4\,|a_2 b_3 c_4 d_5 e_6| \quad \text{when} \quad |b_2 c_3 d_4 e_5 f_6| \text{ is skew:}$$

$$\sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| = -2\,|a_2 b_3 c_4 d_5 e_6| \quad \text{when} \quad |b_2 c_3 e_5 f_6| \text{ is skew:}$$

$$\sum \left|\begin{matrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{matrix}\right| = -2\,|a_2 b_3 c_4 d_5 e_6|_{a_2=0} \quad \text{when} \quad |c_3 d_4 e_5 f_6| \text{ is skew.}$$

On the other hand, the identities of §§ 7, 8 do not in like circumstances give anything new, the results then obtained being simply the theorem regarding the adjugate of a Pfaffian and the theorem regarding a minor of the adjugate.

XII.—Scottish National Antarctic Expedition: Tardigrada of the South Orkneys.

By **James Murray**. *Communicated by* W. S. Bruce. (With Four Plates.)

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Introduction.

While engaged in investigating the Tardigrada of the Scottish Lochs, I was desirous of comparing our Tardigrade Fauna with that of other parts of the world, and it occurred to me that the then recently returned Scottish Antarctic Expedition might furnish some suitable material. On applying to Mr R. N. Rudmose Brown, in the absence of Mr Bruce, I was courteously supplied with various samples of moss which I judged likely to contain Tardigrada.

On examining this moss it was found that Tardigrada were indeed numerous in it, and although not in very great variety, some of the forms were of considerable interest.

The moss had not been collected with a view to the study of its microfauna, but solely as botanical specimens, and was therefore impregnated with some preservative which had killed all the adult animals and most of the eggs. This is unfortunate from the point of view of the present investigation, as I should otherwise have been able to hatch out the Tardigrada and other animals and study their development. A much more complete account of the Tardigrada could in that case have been given.

Besides Water-Bears and their eggs, there were numbers of Bdelloid Rotifers and eggs, Nematodes of at least two species, Rhizopods, and, lastly, very many Mites of at least four species.

The eggs of the Mites seemed to be most impervious to the preservative, and many hatched out, but were very quickly killed by the trace of the naphthaline in the water. The only other animals seen alive were one Bdelloid of the genus *Rotifer*, and a Nematode, which moved feebly for a short time after moistening.

The adult Tardigrada were in very poor condition, most having been long dead, and the flesh all reduced to a formless paste. In this condition, when the specimens were subjected to pressure, all the details of internal structure were lost, and the most useful method of discriminating species rendered of no avail. Even the tough, hard parts of the teeth and pharynx were partially wasted away. The basal portions of the teeth had in most cases merged in the general paste, though the distal parts were intact. The detail had therefore to be studied under moderately low powers, and without exercising much pressure.

A few examples were in that state of rigor so characteristic of Water-Bears, in which the internal parts are in good order, and may be better studied than in active animals,

and may be subjected to pressure, in order the better to study the details. This state has a curious resemblance to rigor mortis. All vital functions appear to be totally suspended; the animal is rigid, and it is impossible to tell whether it is alive or dead. From this apparently lifeless condition a few taps on the coverslip will often rouse it to full activity. No example of the Antarctic Tardigrada revived in this way. The eggs were in better condition, owing to the protection afforded by their shells, but none of them hatched or showed any movement of the contained embryos. The genera *Macrobiotus* and *Diphascon* were very abundant, two species of the latter and several of the former being found. Eggs of *Macrobiotus* were also plentiful. *Echiniscus*, on the other hand, was very scarce, only some half dozen examples being found, which did not differ conspicuously one from another, though no two were quite identical.

Fifteen forms in all were studied. Though these were clearly distinct, they were not in all cases recognisable. Only two could be identified with any certainty as known species. Three others were so abundant and in such good preservation that they could be pretty fully studied, and are here described. Some of the others are as certainly distinct from any known species, but the examples being imperfect, it is not considered desirable to name them.

All, however, are figured, so that it will be easy to identify them when further opportunities occur to study the fauna of the region.

Three of the eggs figured may belong to three of the species incompletely described. If this duplication has occurred, the number of distinct species observed will be reduced to twelve.

Genus Echiniscus.

The genus was very poorly represented, only some half dozen examples being found, all but two being incomplete skins, and in such bad condition that it is impossible to describe them, though some of them have peculiarities which lead me to think they are new species. The two well-preserved examples were identical, and are, I think, of an undescribed species.

No species belonging to the *Arctomys* group (having no setæ or spines except the six on the head) was found. All four forms observed had some dorsal or lateral processes besides those on the head.

Echiniscus meridionalis, n. sp. (Plate I. fig. 1*a* to 1*d*.)

Specific Characters.—Small, plates ten, arrangement normal; three median plates, each plate of the first pair with two setæ, lateral short, dorsal long, each plate of second pair with two short spines, one lateral, one dorsal, a long incurved seta on each of the anal angles (*i.e.* where tail-piece joins lumbar plate); lumbar plate trifoliate, facetted, fringe on last legs of few (about five), very broad spines; inner claws with small decurved

barbs; head setæ long, with expanded base, and separate palp alongside; palp on first leg, none seen on last leg.

Length of one example 164 μ, of the other 200 μ. Fringe absent from the smaller one, obvious on the larger, no other difference. Both appeared as if they might be alive, but in the state of rigor. They did not, however, wake up. The flesh was not wasted as in all the other Tardigrada found, and I was able to mount them. The colour is yellowish, the granules very small.

On account of variability of the processes of Echiniscus, and possible changes in the course of development, Professor RICHTERS advises that no species be described as new unless we have evidence of maturity in the presence of skins with eggs, or there are striking peculiarities of some sort. I have shown, further (2), that even after maturity is reached there may be further development of the processes, as well as great increase in size, during successive moults.

As the eggs have not been seen, this species must be distinguished by the various processes, the arrangement of which does not closely approach any described species. It is nearest to *E. merokensis*, Richters (13), but differs in many little points. That species has the lateral setæ after the first paired plates longer that the dorsal, lacks the lateral short spines after the second paired plates, has a straight spine on the outer claws, and is figured as coarsely granular. Still closer is the resemblance to an undescribed species of which Mr BRUCE made a sketch in Franz Josef Land, but that also has the lateral setæ of the first paired plates longer than the dorsal, has lateral setæ instead of short spines at the second paired plates, etc.

The lumbar plate of *E. meridionalis* has five facets, one dorsal, two lateral, and two posterior (forming the tail-piece), and the species figured by Mr BRUCE corresponds in this respect.

Echiniscus, sp. (Plate I. fig. 4.)

Specific Characters.—Of medium size, plates ten, arrangement normal, granules small. Processes,—on each plate of first pair a long dorsal seta, and a small one close beside it, on each plate of second pair a small triangular dorsal tooth, on the lumbar plate a pair of very long curved setæ, each with a short branch about the middle, 3 median plates. The species has no close resemblance to any known species, and the peculiar branch, like the tine of a stag's horn, on the curved lumbar seta, might suggest such a name as "the Stagshorn *Echiniscus*" (*Cervicornis*). As, however, the study is so incomplete, and the head and legs have not been seen, so that we know nothing of the head setæ, fringe, or claws, it would be premature to give the form a name. I know of no species described which has branched setæ, though *E. Duboisi* (8) has serrate spines.

Echiniscus, sp. (Plate I. figs. 2*a*, 2*c*.)

Description.—Plates nine, normally placed, two median, finely granular, lumbar plate trifoliate, fringe on fourth legs, inner claws with small decurved barb. Processes,—on each plate of first pair a long dorsal and a long lateral seta, on each plate of second pair a small dorsal, triangular tooth, a pair of long curved setæ on the lumbar plate.

This animal has no very marked peculiarities, and till it is more fully known it cannot be determined whether it is identical with or related to any described species. These *Echiniscus* skins, in poor condition, may have lost some setæ which they possessed in life, and it would therefore be hazardous to attempt to identify them in their present state. No species described precisely agrees with it.

Echiniscus, sp. (Plate I. figs. 3*a*, 3*b*.)

Description.—Small, nine plates, two median. Processes,—lateral seta on each plate of first pair, no processes on second pair, pair of long setæ on lumbar plate. Granules of moderate size, interrupted at the line of junction of the tail-piece with the lumbar plate, which is deeply trifoliate. Fringe of broad spines on fourth leg, no barbs seen on any claws. No dorsal processes.

This species also has no conspicuous peculiarity. It is the only *Echiniscus* I have seen in which there is a line free from granules at the base of the tail-piece, though RICHTERS gives this character for several species. I am not inclined to put much value on this feature for specific distinction, as I think it likely it may be an age-mark.

In species of *Echiniscus* destitute of dorsal processes, the lateral processes are usually also absent, except on the head. The possession of lateral setæ, with lack of all dorsal processes and barbs on the claws, and the interruption of the granulation at the base of the tail-piece, sufficiently distinguish this from all previously described species. If the example is young, it may be that the species acquires dorsal processes and barbs at later moults.

The setæ and spines of *Echiniscus* tend to increase in length at each moult, and new ones may appear, while the straight barbs of the outer claws, in those species which possess them, sometimes appear only at a late stage. The decurved spines or barbs of the inner claws, present in the great majority of species, appear, on the other hand, to be of more importance to the larva, and are generally reduced in size in the adult.

Genus MACROBIOTUS.

Animals of this genus were extremely numerous, and several species of both sections were found. In the first section the eggs are laid free and singly, and are covered with processes. Three distinct eggs indicated as many species belonging to this section, but

in only one of these species did I succeed in connecting the egg with the animal which produced it. The others must remain unidentified till the living animals can be studied.

In the other section the smooth oval eggs are deposited several together in the moulted skin, and here again, though several species were seen, only one could be fully studied, and that appears to be a hitherto undescribed species.

In all the species figured it will be noticed that the pharynx is relatively extremely small. The size of the pharynx has been used by authors as a specific character. Of little service at any time, owing to variability, the size of the pharynx is quite valueless in the case of the South Orkneys species. In these, I think, the muscular bulb is greatly contracted.

A. Spiny Eggs, laid singly, free, not in the moulted skin.

Macrobiotus furcatus, n. sp. (Plate II. figs. 6*a* to 6*d*.)

Specific Characters.—Large, hyaline, in form like *M. hufelandi*, with claws in pairs, which are united half way up as in that species, but with stronger supplementary points. Teeth slightly curved, with a small furca. Pharynx very small, oval or rhomboid, thickenings in each row,—first, short nut next gullet, then three equal rods, about twice as long as broad, then a very obscure small nut. Dark eyes. Eggs spherical, with conical processes, which are dichotomously branched twice or thrice. Length about 600 μ, pharynx of adult 46 μ long.

By far the most abundant Tardigrada collected. The eggs were still more numerous than the adults. By squeezing one fully developed young out of the egg, I was able to establish the identity of structure both of claws and pharynx with the commonest adult *Macrobiotus* in the collections.

This species may be regarded as the South Orkney representative of *M. hufelandi* (14), with which it has affinities in all points of structure. The processes on the egg are most conspicuously different, yet their form is the same, only they are dichotomously divided at the apex. Most of the processes are twice furcate, with slight traces of a third division. Some have a perforation lower down than the first fork. The egg measures 83 μ without the spines, 105 μ over the spines. The pharynx differs in the complete separation of the first two rods, which in *M. hufelandi* are almost joined. The pharynx is relatively much smaller, but it is probably much contracted.

The claws are very similar to those of *M. hufelandi*, but the supplementary points are almost as large as the main claw. I could never see clearly two distinct supplementary points on the same claw, as Richters found to be the case in *M. hufelandi*; but the appearance in optical section (fig. 6*c*) supports the belief that there are two here also. Owing to diffraction effects the true form of supplementary points on the claws of *Macrobiotus* is difficult to make out.

The processes of the egg have a very remote resemblance to those of *M. granulatus*,

Richters (9), but this does not indicate any affinity whatever, as the entire organisation is different. The processes in that species are divided into several points, but they are not dichotomous.

Macrobiotus echinogenitus, Richters. (Plate IV. figs. 14*a* and 14*b*.)

A single egg, the largest seen, might belong to this extremely variable species, but no adult animal at all resembling *M. echinogenitus* in structure was found.

The egg measures 102 μ without the spines, 120 μ over the spines.

The processes are conical, with rounded tops. They are not unlike those figured by Plate as the egg of *M. hufelandi* (5).

It is only on account of the great variability of the egg of *M. echinogenitus*, in size as well as in the form of the processes, that I for the time being include this large egg under that species. I expect to find that the animal which produces this egg is a distinct species.

In a previous paper (4) dealing with *M. echinogenitus*, I was led by an error in translation to entirely misrepresent Professor Richters' work on this species and *M. hufelandi*.

In reading his original description (9), I understood Professor Richters to say that the two species were so close that they could only be separated by the totally different form of their eggs, and so omitted to read carefully the remainder of the description, in which he shows that both claws and pharynx are quite different in the two species. The claws of *M. hufelandi* are joined for half their length, those of *M. echinogenitus* form a V, jointed only as the bases. The pharynx of *M. echinogenitus* is variable, presenting three distinct forms, each associated with a different size of egg. If other species, as is likely, have also series of distinct forms of pharynx, the value of this otherwise excellent character for specific distinction is lessened. Everything has yet to be learned as to the cause and meaning of this variation, especially of the remarkable 'simplex' form.

I have seen hatch from a sufficiently typical *hufelandi* egg an animal with a pharynx like one of the forms figured by Richters for *echinogenitus* (13, Plate 16, fig. 16).

The claws appear to be the least variable structures of *Macrobiotus*, and by their form *M. hufelandi* and *M. echinogenitus* can be most readily distinguished.

Macrobiotus, sp. ? (Plate IV. figs. 15*a* to 15*c*.)

This species we only know from the egg, the very distinct structure of which indicates a good species, but none of them contained a fully developed young, so the identification could not be completed. The processes consist each of a hemispherical base, from the summit of which rises a pair of ovate bodies resembling leaflets, which meet below and diverge above. The egg measures 80 μ without the processes, and 95 μ over them.

The furcate process has some resemblance to that of *M. furcatus*, but the larger base and the definite form of the leaflets leave no doubt that it is distinct. Very few examples were seen.

Macrobiotus, sp. ? (Plate IV. fig. 16.)

Known only from the egg, which closely resembles the last (fig. 15), of which it is possibly a variety. The egg is of the same size, and has processes likewise consisting of a hemispherical base and bifid process. The differences are that the basal part is relatively much larger, and that the divisions of the bifid portion are rounded instead of pointed.

Macrobiotus, sp. ? (Plate III. figs. 10*a* to 10*b*.)

Description.—Claws of the *hufelandi* type, but, like *M. furcatus*, the supplementary points are stronger, pharynx round, two nearly equal rods in each row, each about three times as long as broad, teeth curved, no bearers seen.

A large smooth-skinned animal, reaching to 520 μ in length. It may be only a variety of *M. furcatus*. The structure of the pharynx is sufficiently distinct, but this is subject to variation in some species at least, as RICHTERS' *M. echinogenitus* (see *Fauna Arctica* (13)). As there are two spiny eggs unaccounted for, the probability is that this is the animal that lays one of those.

One pair of claws is larger than the other, which is unusual with claws of the *hufelandi* form.

Macrobiotus, sp. (Plate III. figs. 9*a* to 9*b*.)

Description.—Claws quite like the last, of the *hufelandi* type, but with stronger supplementary points and one pair larger than the other. The pharynx also, like the last (fig. 10*a*), has two rods in each row. The differences are that the pharynx is elliptical instead of round, and the first rod of each row is longer, narrower, curved, and thinned close to the end of the gullet.

B. EGGS SMOOTH, LAID IN THE MOULTED SKIN.

Macrobiotus asperus, n. sp. (Plate II. figs. 5*a* to 5*e*.)

Specific Characters.—Large, dark brown. Claws in two similar pairs, joined only near the base, one member of each pair much longer than the other, and with fine supplementary point. Teeth curved, with bearers. Pharynx nearly round, with three short rods in each row of thickenings; rods nearly equal, about twice as long as broad, the first a little shorter. Skin covered on back and sides with somewhat large tubercles, irregularly scattered; ventral side and legs smooth. Eyes dark.

Length up to 600 μ, pharynx (of small example) 50 μ long; claws 24 μ to 34 μ; those of first legs shortest and of last legs longest.

The granules or tubercles were hemispherical, and appeared of soft texture. Owing to their bad state of preservation, nothing could be inferred from this as to their original condition.

The previously described tubercled species of *Macrobiotus* are *M. tuberculatus*, *M. sattleri*, *M. ornatus*, *M. papillifer*, *M. annulatus*, *M. granulatus*, *M. crenulatus*.

M. granulatus and *M. crenulatus* are sufficiently separated by the wrinkled or spiny crescent in front of each pair of claws. *M. tuberculatus*, *M. sattleri*, *M. papillifer* by the large size of the tubercles, which are symmetrically arranged in longitudinal and transverse rows. There remain only *M. annulatus* and *M. ornatus*, which have the tubercles relatively small. *M. annulatus* has the tubercles very regularly spaced, falling into definite transverse annulæ, following the segments, and extending also over the ventral surface.

M. ornatus, var. *verrucosus*, has the thickenings in the pharynx of a different form, that of nearly round nuts. The ill-understood *M. oberhäuseri*, of which such conflicting accounts are given, is sometimes, according to RICHTERS (10), partly papillose. *M. asperus* may be distinguished from it by the structure of the claws. Both pairs are alike, with one of each pair nearly twice as long as the other. *M. oberhäuseri* has the elongate claw on only one pair on each foot. From all of those species there are other differences which it is needless to detail. Fairly abundant when the mosses were first examined, no example has been found recently. The skins which I tried to preserve became quite collapsed, shapeless, and unrecognisable.

Macrobiotus, sp. (Plate III. figs. 7*a* to 7*d*.)

Description.—Large, very similar in claws and pharynx to *M. asperus*, but skin not granular. One pair of claws is a little larger than the other. The teeth are nearly straight, but abruptly bent near the throat; their bases diverge widely. Four eggs were found in one skin. It reaches 570 μ in length.

Macrobiotus? sp.? (Plate III. figs. 8*a*, 8*b*.)

Description.—Small, claws of two pairs joined only at base, smaller pair of nearly equal claws, larger pair with one very long claw. Eggs elliptical, laid in the skin.

As this species is only known from skins containing eggs, the description cannot be completed. The claws are of what I take to be the *oberhäuseri* pattern, not, as originally described (1), quite separate, but joined at the base. This arrangement resembles the *Diphascon* claw, as I understand it, but the mode of union of the two

claws is not quite the same. In all species of *Diphascon* known to me the long claw appears, when seen from the side, to spring from the middle of the shorter claw. This animal may be a *Diphascon*.

Genus Diphascon (5).

Two species only were distinguished, and both were identified as known species, though they possessed some little peculiarities.

The genus rests on slight and doubtfully stable characters. The elongated, flexible portion of the gullet, intervening between the teeth stays and the pharynx, is the sole character on which Plate (5) founded the genus. None of the recognised species of *Diphascon* have ever, so far as I am aware, been found without this flexible portion, though *D. angustatum* has this portion very short and only slightly flexible. None of the six species known to me would, if deprived of the flexible gullet, be rendered identical with any species of *Macrobiotus*.

Some species of *Macrobiotus*, on the other hand, exceptionally develop the flexible gullet. I have seen *M. macronyx* and *M. ornatus* in this condition.

In view of this one character, then, the species of *Diphascon* would be only those in which there is normally a long flexible gullet, which *Macrobiotus* might exceptionally have. In that case the genus would have to be abandoned, as was necessary with *Doyeria*.

All the species of *Diphascon* have one very elongate claw on each foot. This is also a characteristic of *M. oberhäuseri*. The long claw and one short claw of that species are said to be quite separate and independent. I have seen no species in this condition.

In *Diphascon* the pair of short claws are united at the base. The pair to which the elongate claw belongs are also joined, but not at the base. Seen from the side, under pressure (Plate IV. fig. 17), the long claw seems to be joined to the back of the short one half way up the latter. If this structure of claws proves to be distinct from that of *M. oberhäuseri*, it may be possible to retain the genus on this character.

Diphascon chilenense. Plate (5). (Plate IV. figs. 12*a* to 12*c*.)

Specific Characters.—Small, short, broad; one pair of claws equal, the other with one longer claw, having small supplementary point. Teeth small, curved, with bearers, gullet slender, pharynx round, rods five in each row, short, scarcely separate.

Size, up to 240 μ long. The number of nuts in the pharynx is subject to variation, but they are always sub-equal, short, roundish, and touching, or nearly so. It is relatively the broadest of the genus (except *D. bullatum* (3)). The S. Orkney examples are much contracted, and this affects the breadth more than the length, so that they appear narrower than usual.

Diphascon alpinum, Murray (4). (Plate IV. figs. 11*a* to 11*c*.)

Specific Characters.—Long, narrow, whitish or hyaline; one pair of claws, short and very thick, with conspicuous short supplementary point on one claw, the other pair with one very long claw, having a fine supplementary point. Teeth short, curved, with bearers; gullet very long, slender, pharynx shortly oval, three rods and a short nut in each row. The rods increase both in length and thickness from the first to the third, which is about three times as long as broad.

The S. Orkney examples are much larger than the Scotch ones, reaching 360 μ in length. The only other difference is the fourth small nut in the rows of pharyngeal thickenings. This little nut at the end of the row is in many species of Tardigrada very obscure, very doubtfully of the same structure as the other rods, and at any rate of too uncertain a character to be regarded as of any specific value.

Notes.

Taking a general view of the preceding somewhat meagre list of Tardigrada, the most striking feature of it is its very slight correspondence with the Tardigrade fauna of other parts of the world. It differs not only from the fauna of the temperate regions, which we know best, and from that of the arctic region, which has been pretty well studied, but from that of the only other part of the antarctic region which has been studied (12); indeed it differs more from the last than from the others.

Every one of those regions has a number of peculiar local species, mingled with others which are widely distributed.

Only two of the S. Orkney water-bears have been identified, and a third doubtfully. We cannot, however, suppose that we have anything like a complete, or even a fair, knowledge of the Tardigrada of the South Orkneys. The fifteen forms enumerated were obtained practically from one large tuft of moss. A second minute scrap yielded only a few examples, which were of species plentiful in the larger sample. If mosses from a variety of situations could be examined in the fresh condition, it is likely that others of the widely distributed kinds would be found, as well as perhaps still other local species.

The Tardigrada would appear to be best adapted to live in temperate or cold regions. They are very numerous in Scotland; in Spitzbergen they are also plentiful and the largest known species are found; while in the only parts of the southern hemisphere which have been studied, the Tardigrada are a conspicuous element in the moss-fauna.

A large series of samples of moss from India has been recently examined for Tardigrada, and though some of them came from elevations of 7000 to 8000 feet, near Darjeeling, and there were a few peculiar species, they were, on the whole, very scarce.

No doubt, with fuller information as to the many species here referred to as "doubtful," several could be referred to known species, though several others are almost certainly

distinct. In the case of *Macrobiotus* which lay spiny eggs, the presence of a known species is generally first indicated by the eggs. It is notable that in the S. Orkney moss no single example of such unmistakable eggs as those of *M. hufelandi*, *M. intermedius*, and *M. echinogenitus* (type) was seen.

The South Orkneys are situated outside the Antarctic Circle, but within the ordinary limits of drift ice. I have found only one record of a Tardigrada from within the Antarctic Circle, viz. *Macrobiotus antarcticus*, found by Professor RICHTERS in moss from the Gaussberg.

In the collections made by the German South-Polar Expedition on various islands in the Southern Ocean, Professor RICHTERS has found altogether eleven species, viz. *Macrobiotus hufelandi*, Sch., *M. oberhäuseri*, Doy., *M. tetradactylus*, Greeff, *M. intermedius*, Plate, *M. sattleri*, Richters, *M. echinogenitus*, Richters, *M. vanhoffeni*, Richters, *M. antarcticus*, Richters, *Echiniscus arctomys*, Ehr., *E. kerguelensis*, Richters, E. sp.? (not yet named). To this list I understand Professor RICHTERS will make some additions in a more detailed memoir to be published at an early date. EHRENBERG recorded a *Macrobiotus* from St Paul Island as doubtfully *M. hufelandi*.

The meagre materials available for the study of the Tardigrada of the Southern Ocean are still sufficient to indicate a Tardigrada fauna comparable for variety with that of the arctic regions, though the species yet known are not quite so numerous.

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(4) „ „ "Scottish Alpine Tardigrada," *Ann. Scot. Nat. Hist.*, 1906, p. 25.
(5) PLATE, L. H., "Naturgeschichte der Tardigraden," *Zool. Jahrb.*, Bd. iii., *Morph. Abt.*, 1888, pp. 487–550.
(6) RICHTERS, F., *Ber. Senckenbg. Natf. Ges.*, 1900, p. 40.
(7) „ „ "Fauna der Umgebung von Frankfurt-a-M.," *Ber. Senckenbg. Natf. Ges.*, 1902, pp. 8–13.
(8) „ „ "Neue Moosbewohner," *Ber. Senckenbg. Naft. Ges.*, 1902, pp. 23, 24.
(9) „ „ "Nordische Tardigraden," *Zool. Ang.*, Bd. 27, 1903, p. 168.
(10) „ „ "Eier der Tardigraden," *Ber. Senckenbg. Natf. Ges.*, 1904, p. 59.
(11) „ „ "Verbreitung der Tardigraden," *Zool. Ang.*, Bd. 28, 1904, p. 347.
(12) „ „ "Vorläufiger Bericht über die Antarktische Moosfauna."
(13) „ „ "Fauna Arctica," Bd. iii., 1904, pp. 495–508.
(14) SCHULTZE, C. A. S., "Macrobiotus hufelandi," *Isis* of Oken, 1834, p. 708.

EXPLANATION OF PLATES.

Plate I.

1. *Echiniscus meridionalis*, n. sp.

a, lateral view.
b, dorsal view.
c, last leg, with fringe.
d, outer and inner claw of last leg.

2. *Echiniscus*, sp. ?

a, dorsal view.
b, outer and inner claw of last leg.

3. *Echiniscus*, sp. ?

a, dorsal view.
b, outer and inner claw.

4. *Echiniscus*, sp. ?

Plate II.

5. *Macrobiotus asperus*, n. sp.

a, lateral view.
b, dorsal view.
c, claws, seen from front.
d, claws, seen from side.
e, teeth and pharynx.

6. *Macrobiotus furcatus*, n. sp.

a, dorsal view.
b, teeth and pharynx, under pressure.
c, claws.
d, furca of tooth.

Plate III.

7. *Macrobiotus*, sp. ?

a, dorsal view.
b, teeth and pharynx.
c, claws.
d, larger pair of claws.

8. *Macrobiotus*, sp. ?

a, skin with three eggs.
b, claws of 4th leg.

9. *Macrobiotus*, sp. ?

a, gullet and pharynx.
b, claws.

10. *Macrobiotus*, sp. ?

a, teeth and pharynx.
b, claws.

Plate IV.

11. *Diphascon alpinum*, Murray.

a, dorsal view.
b, teeth and pharynx.
c, the shorter pair of claws.
d, claws of 4th leg.
e, longer pair of claws.

12. *Diphascon chilenense*, Plate.

a, dorsal view.
b, teeth and pharynx.
c, claws.

13. *Macrobiotus furcatus*, n. sp., egg.

a, complete egg.
b, three of the furcate processes, from the side.
c, two processes, seen from above.

14. *Macrobiotus echinogenitus*, Richters ?

a, the egg.
b, one process.

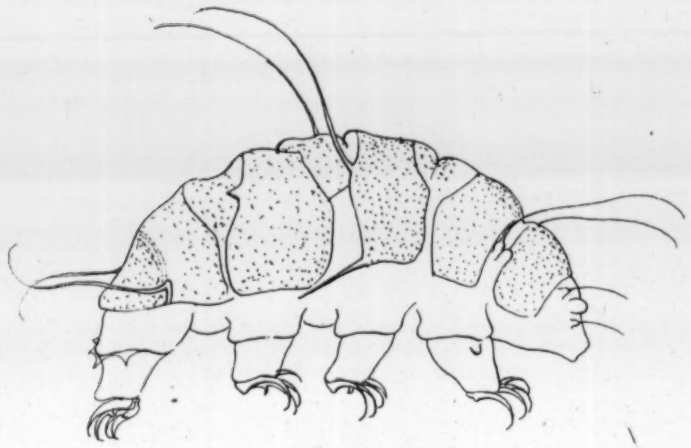
15. *Macrobiotus*, sp. ? egg.

a, the egg.
b, a process, lateral view.
c, a process, seen from above.

16. *Macrobiotus*, sp. ? egg, process.

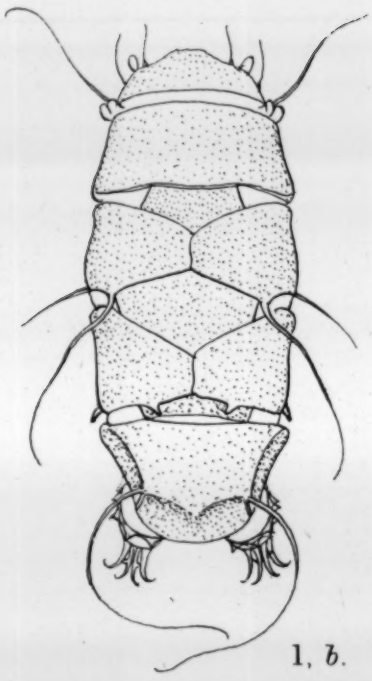
17. *Diphascon*, long pair of claws of an undescribed species.

MURRAY: TARDIGRADA OF THE SOUTH ORKNEYS. — PLATE I.

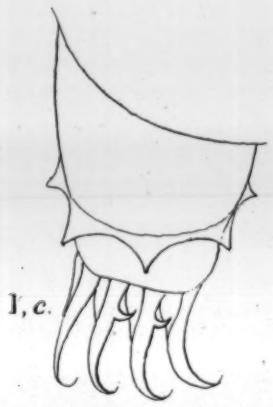


1, *a*.

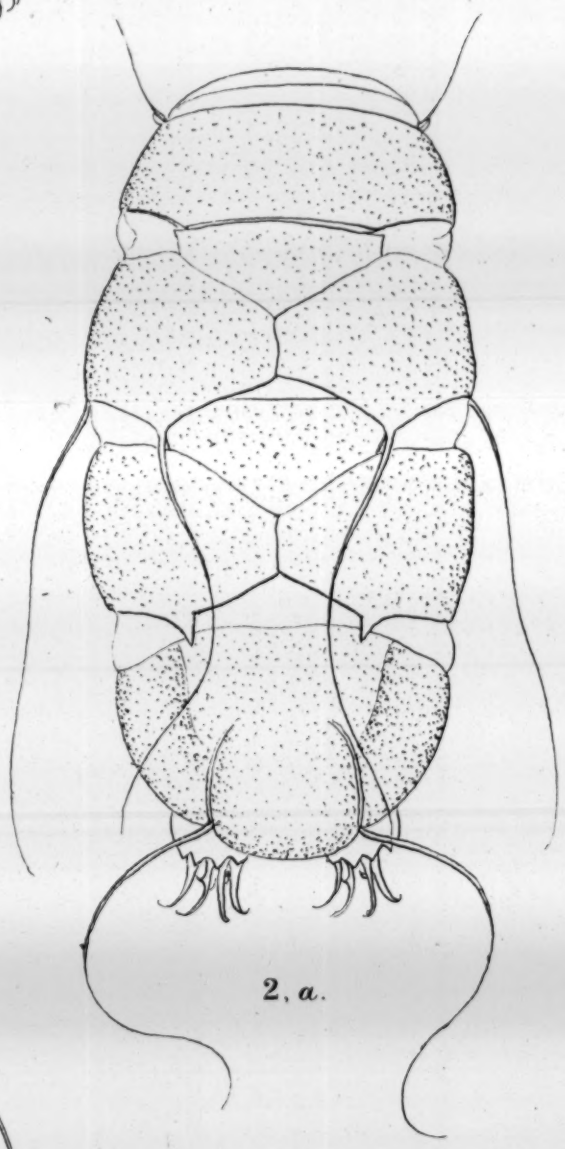
1, *d*.



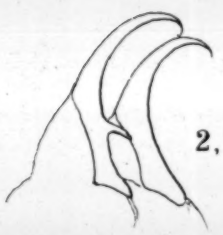
1, *b*.



1, *c*.



2, *a*.



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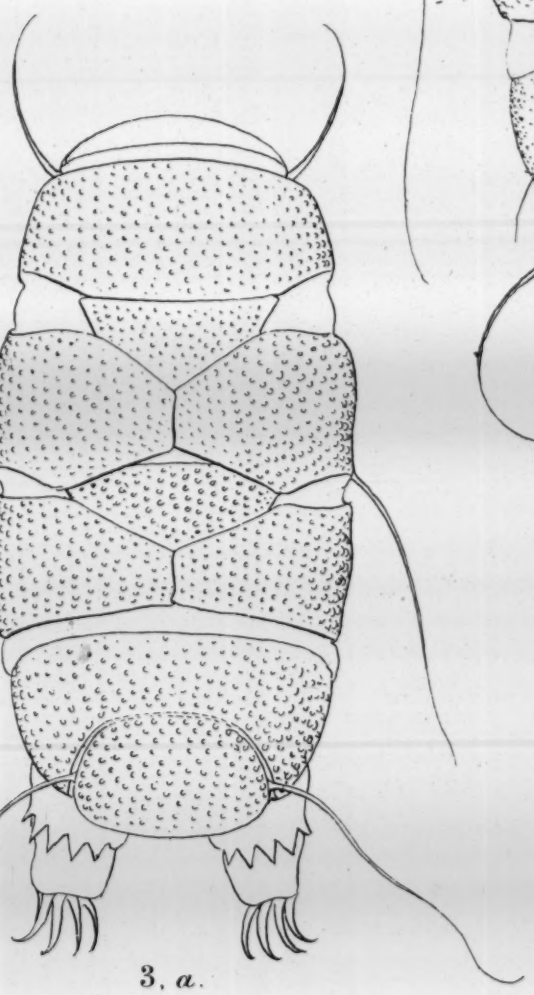
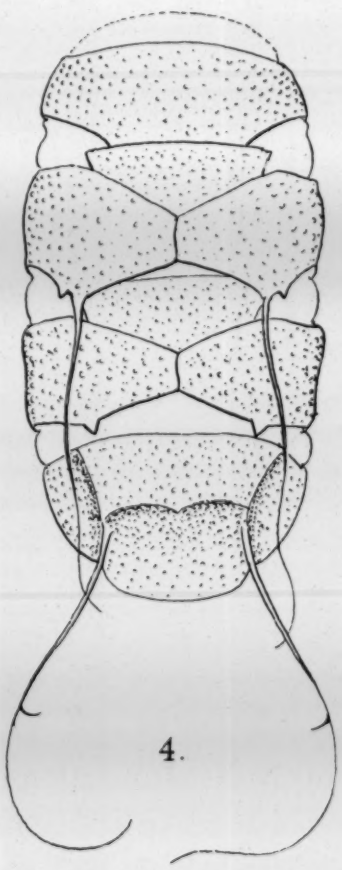


3, *a*.

3, *b*.

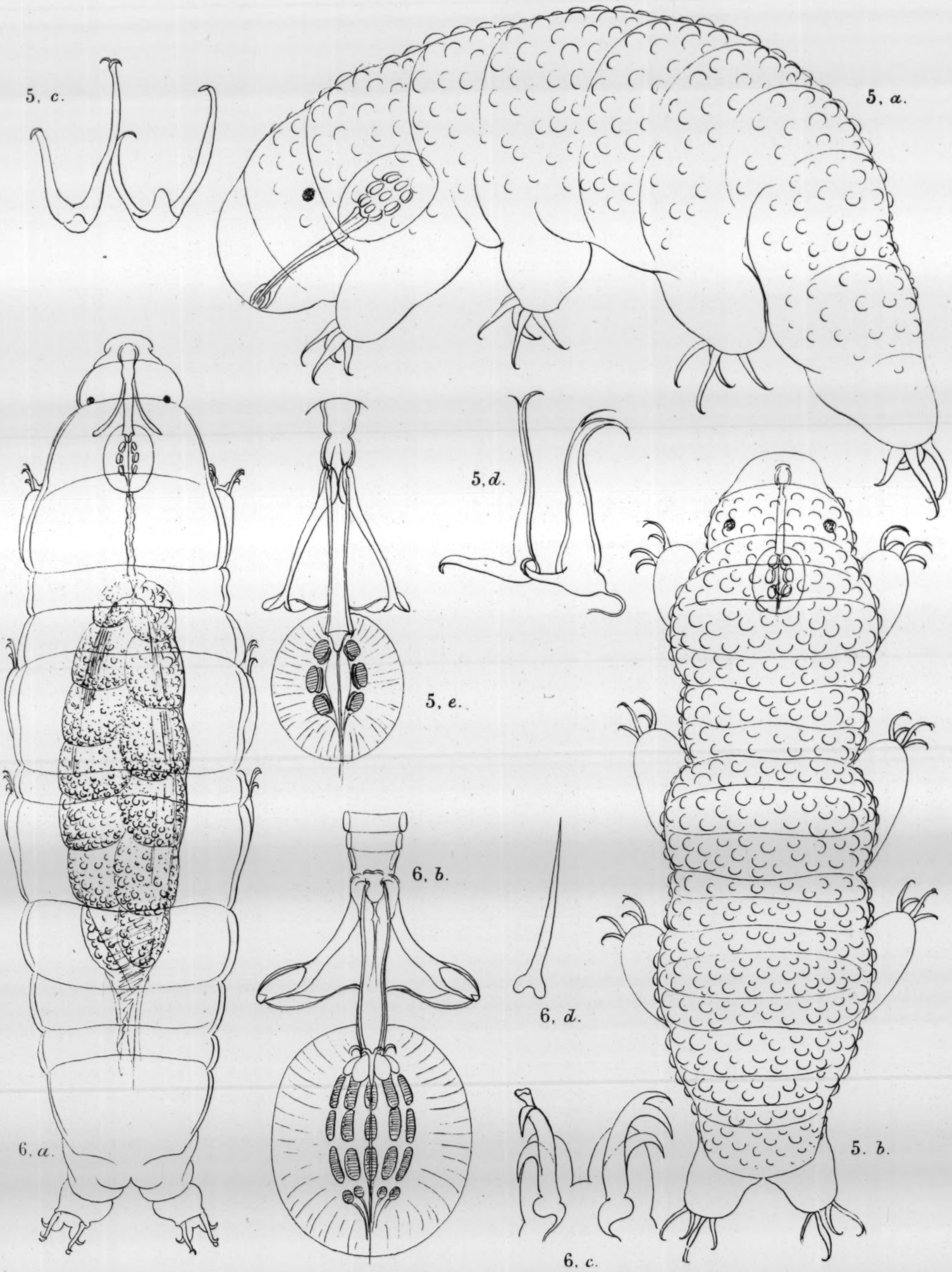


4.

McFarlane & Erskine Lith. Edin.r

1. ECHINISCUS MERIDIONALIS, n. sp. 2, 3, 4. ECHINISCUS, sp. ?

MURRAY: TARDIGRADA OF THE SOUTH ORKNEYS. — PLATE II.

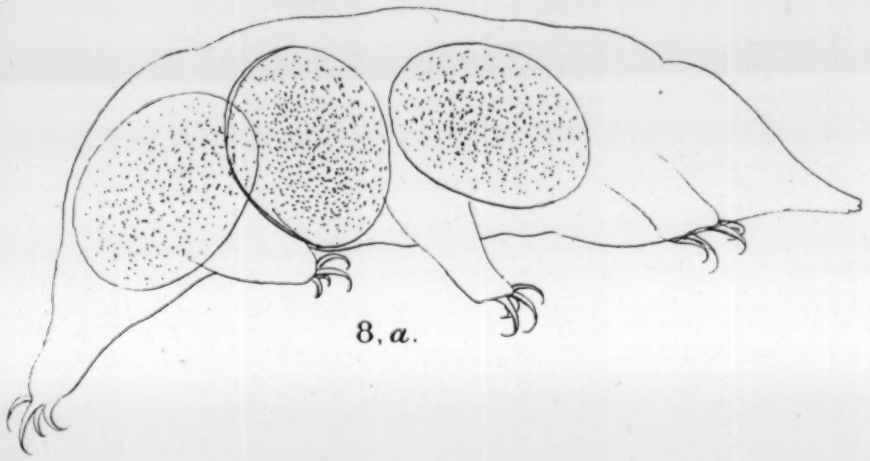


5, MACROBIOTUS ASPERUS, n. sp.

6, MACROBIOTUS FURCATUS, n sp.

M'Farlane & Erskine Lith. Edin.r

MURRAY: TARDIGRADA OF THE SOUTH ORKNEYS. — PLATE III.



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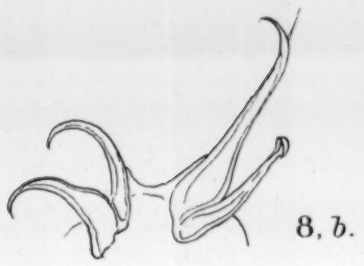
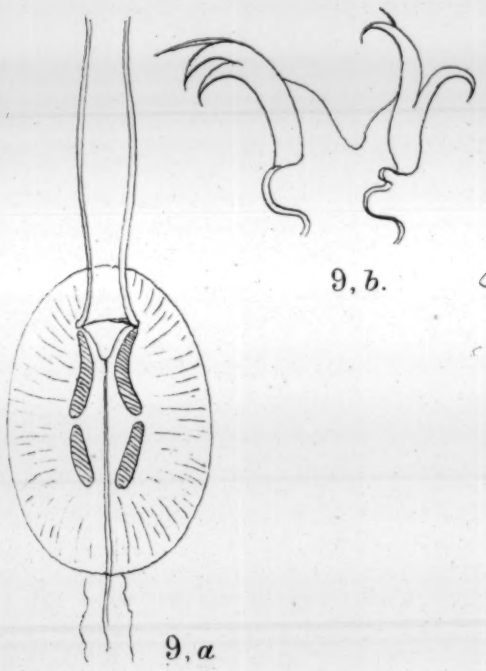
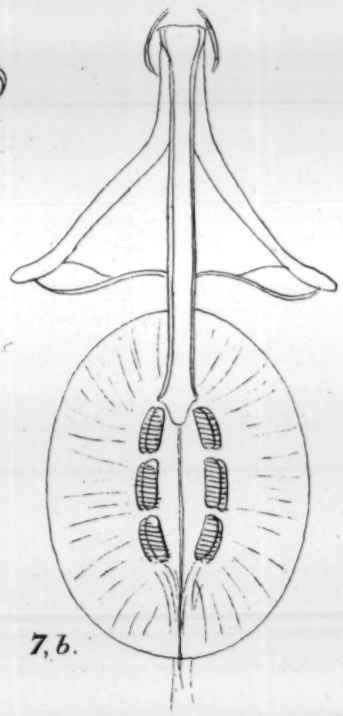


8, *b*.

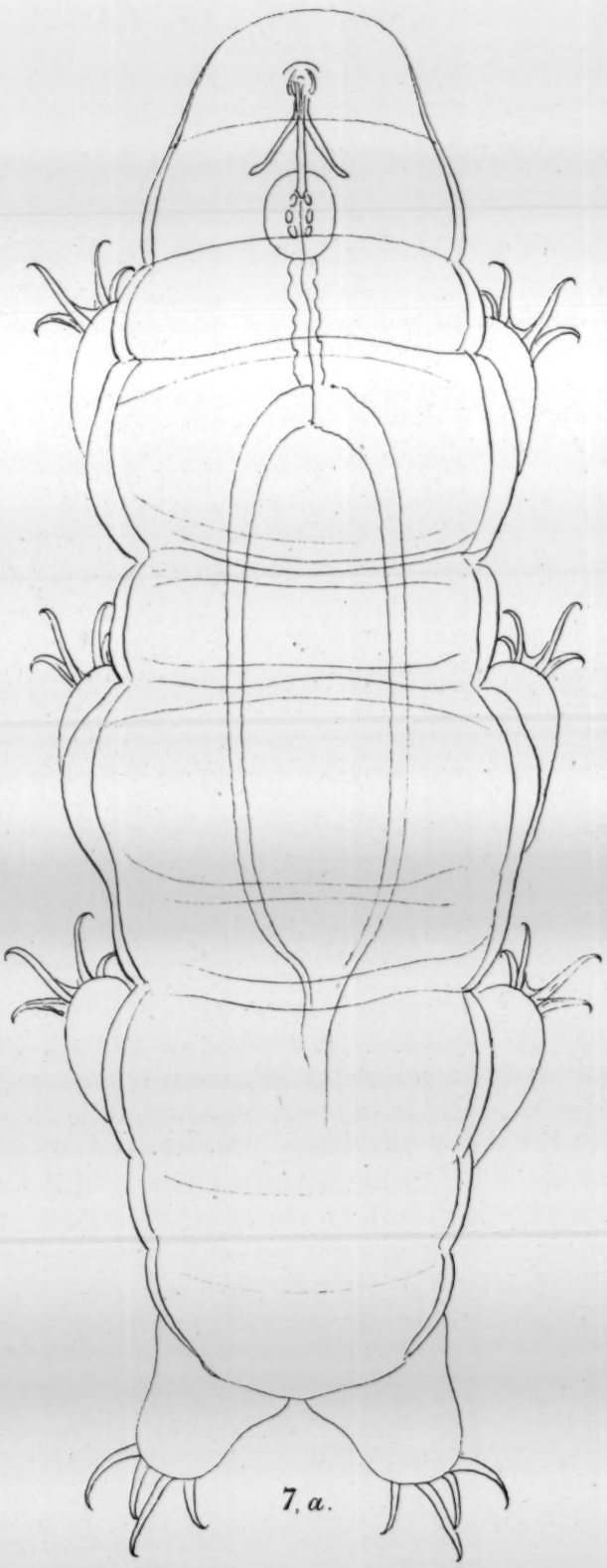


9, *b*.

9, *a*



7, *b*.



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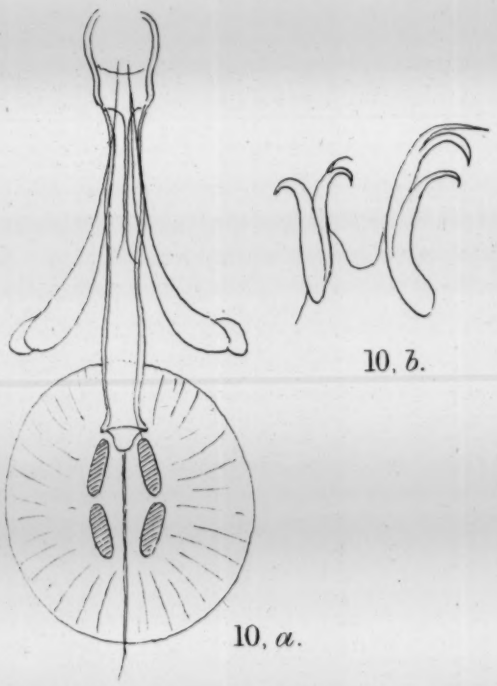


10, *a*.

10, *b*.

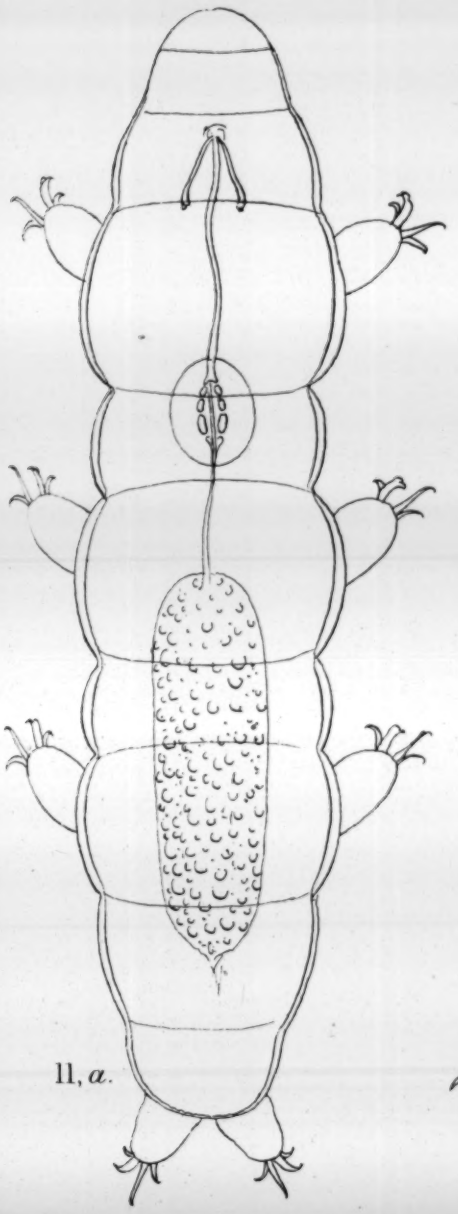
7, *c*.

7, *d*.

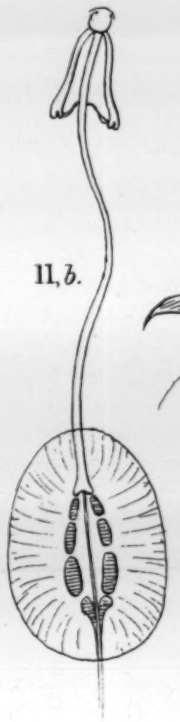
M'Farlane & Erskine, Lith. Edin.r

7, 8, 9, 10, MACROBIOTUS, sp. ?

MURRAY: TARDIGRADA OF THE SOUTH ORKNEYS — PLATE IV.



11, *a*.



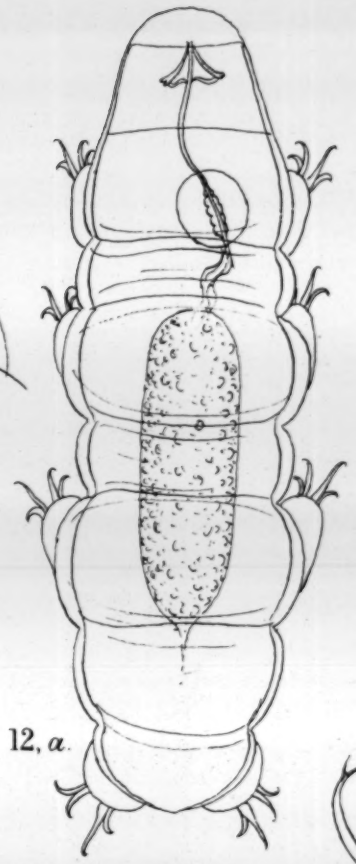
11, *b*.

17.

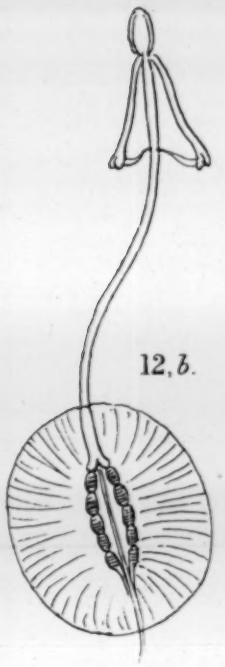
11, *c*.

11, *d*.

11, *e*.

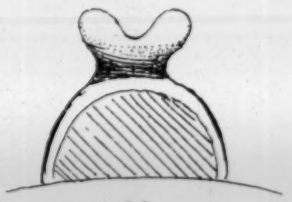


12, *a*.



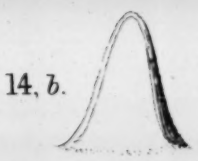
12, *b*.

12, *c*.

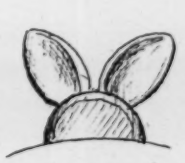


16.

13, *c*.

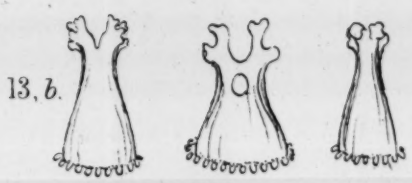


14, *b*.

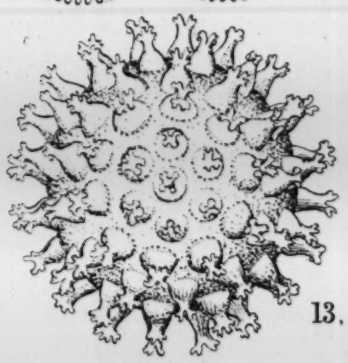


15, *b*.

15, *c*.



13, *b*.



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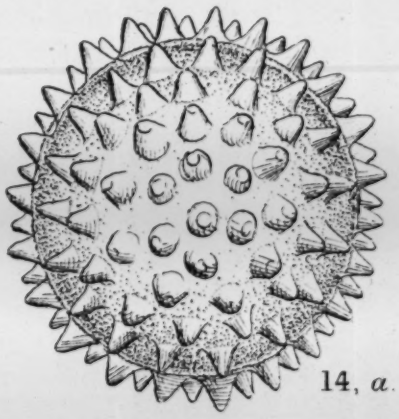

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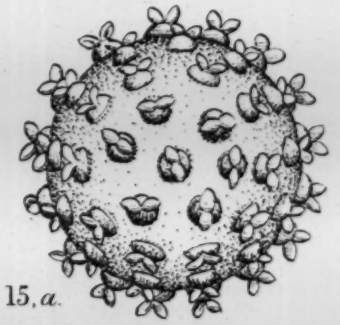

15, *a*.

M^c Farlane & Erskine, Lith. Edin.^r

11. DIPHASCON ALPINUM, Murray. 12, D. CHILENENSE, Plate. 13, MACROBIOTUS FURCATUS, n. sp.
14, M. ECHINOGENITUS, Richters ? 15.16. MACROBIOTUS, sp. ? 17, DIPHASCON, sp.

XIII.—The Plant Remains in the Scottish Peat Mosses.

By **Francis J. Lewis**, F.L.S., Lecturer in Botany, University of Liverpool. *Communicated by* Professor Geikie, LL.D., F.R.S. (With Four Plates.)

PART II.

The Scottish Highlands.

(MS. received June 8, 1906. Read June 18, 1906. Issued separately October 19, 1906.)

An investigation of the peat mosses in some districts of the Scottish Highlands was made in 1905, with a view of comparing the features found there with those already recorded from the Southern Uplands in 1904. The salient feature met with in the Southern districts was the existence in all the older mosses of an upper and lower forest-bed, with a zone of Arctic plants intercalated between. The existence of this Arctic plant bed, stretching at the same horizon through the peat in districts widely separated, indicates a lowering of temperature which must have obtained over much greater areas; for the conditions implied by the presence of an Arctic vegetation at low levels in the South of Scotland would suffice—precipitation being great enough—to produce glaciation in the Highlands. It was desirable to find evidence in the North for or against that view. The work has also been taken up with the object of ascertaining the changes in distribution of the British Flora since late glacial times. In order to do this, systematic investigations must be made, not merely in a few districts, but throughout Great Britain generally. Observations made farther north, in the Shetland and Faröe Islands and in Iceland, might be expected to throw light upon the origin of the flora of Greenland. The Alpine members probably survived on nunataks through the glacial period, but lowland plants must almost certainly have been destroyed by the rigours of that period. Warming (1) brings forward observations which tend to disprove the existence of a land bridge through Scotland, by Shetland, Faröe, and Iceland, to Greenland, and the immigration of the European elements in the Greenland flora along that bridge. Investigation of the peat in those islands would show whether they have formed a link in that hypothetical highway of plant immigration to Greenland.

By the researches of Clement Reid (2) on deposits in Norfolk and the South of England our knowledge of the pre-glacial and early inter-glacial flora has been considerably increased, but nothing is known of its history later than the mid-glacial period. Yet the geological evidence for considerable climatic changes during late glacial and so-called post-glacial times is weighty, and we can hardly doubt that such climatic changes must have produced corresponding changes in the distribution of the

flora. The older peat deposits in Scotland date back to late glacial times. They consist entirely of plant remains, often stratified in the clearest manner, and yield evidence of great changes in the distribution of the flora.

The objects of the present investigation are, then, twofold :—(*a*) to obtain evidence of the changes in distribution which have taken place since the introduction of the present British flora, and (*b*) from those changes to reconstruct the main climatic fluctuations marking the later stages of the glacial epoch. That the peat mosses will yield abundant evidence on these points may be expected from the results already obtained.

It is important to bear in mind that in dealing with plant remains in peat mosses only certain plants are likely to be found—namely, those which either always or occasionally grow on humus. In addition to these, a few seeds of plants growing on the surrounding non-humus-covered ground will probably have been introduced to the peat areas by the agency of animals or wind.

It is only the greater and more widespread changes in vegetation whose records occur in the peat ; many smaller fluctuations, due to modifications of local drainage or alterations in the chemical character of the peat over certain areas, would hardly be pronounced enough to persist for sufficient time to leave any definite record. One of the most important points to be determined is whether the stratification met with is local in character, or whether it occurs over a wider area ? It thus becomes desirable to make a systematic examination of all the peat, taking it district by district. For the purpose of comparing the peat strata in widely separated districts, two well-marked datum lines are available—viz. the lower and upper buried forests. That these represent widespread and considerable changes in the conditions is shown by their occurrence wherever the peat is examined. Where such a buried forest is not found—owing either to the elevation or the slope of the ground not having been favourable to tree-growth—it is represented by a bed of dry humus-loving plant debris, which shows that dry conditions prevailed generally during the period of forest growth.

Method of Survey.—The same general method of procedure for examining the peat deposits in the field and specimen blocks in the laboratory has been followed on this occasion as described in the paper dealing with the South of Scotland (3). The deposits investigated in the North usually lie some distance from any areas of turbaries, and all the deposits have been undisturbed by human agency since their deposition. As sections yield much fuller evidence than borings, they have been made wherever possible. Borings have only been resorted to on the Skye mosses, for, owing to their flat, unbroken character, wet condition, and depth, section-cutting is difficult. The evidence gathered from that region, however, does not rest entirely upon borings, for many sections were made at different points ; borings were only used to obtain evidence of the continuity of the beds found in the sections. So closely are these mosses covered with vegetation that it is often a matter of some difficulty to cut through the thick mat of vegetation to the underlying peat.

The following areas are described in this paper :—

I. Isle of Skye.—(*a*) Peat in the South-East of the island North-West of Broadford.
(*b*) The basaltic plateau on the Eastern side of the island near Portree.
(*c*) The basaltic plateau on the Western side of the island near Loch Bracadale.
II. Outer Hebrides.—The North-West region of North Uist.
III. Caithness-shire.—Between Altnabreac and Scotscalder, on the Highland Railway.
IV. Easter Ross.—The hill district lying to the West of the Kyle of Sutherland.
V. Inverness-shire.—The Spey-Findhorn Watershed.
VI. Inverness-shire.—The Findhorn-Nairn Watershed.

Southern and Central Skye.

(One-inch Ordnance Survey—sheets 71, 80.)—Three different areas were investigated during the field work in Skye: (1) The peat lying to the North-West of Broadford, below Beinn na Caillich and Beinn Dearg, in the South-Eastern part of the island. (2) Peat situated on the basaltic plateau on the Eastern side of the island, a few miles from Portree. (3) Peat on the Western edge of the basaltic plateau in the neighbourhood of Loch Bracadale.

(1) *Peat lying on the North and East of Beinn na Caillich.*

The peat here occurs at 50–700 feet above O.D., on gently sloping ground, with the granitic cones of Beinn na Caillich and Beinn Dearg, rising to 2400 feet in the west. The surface of the moss is in strong contrast to that of the hill-top and hill-side peat in the Northern and Eastern Highlands, and even to many of the hill mosses in the Outer Hebrides. Instead of the deep furrows and high banks of denuded peat, the surface of the moss is smooth and closely covered with vegetation, consisting mainly of *Calluna vulgaris*,* Salisb., *Myrica Gale*, L., *Erica Tetralix*, L. (scanty), *Eriophorum vaginatum*, L., abundance of *Drosera intermedia*, Hayne; *Phalaris arundinacea*, L. (not abundant), and Sphagnum,—a type of plant association very similar to that covering large areas on the mosses lying at 300 feet in Kirkcudbrightshire and Ayrshire. The general depth of the peat varies from 5 to 9 feet, and it rests upon a stiff grey clay, containing many stones and large quantities of grit in the upper layers. The sequence of the strata is the same over the whole of this area, all the sections showing three distinct zones.

Dominant Plants.	Secondary Plants.
1. Recent peat, formed chiefly from Scirpus and Calluna.	1. ...
2. Phragmites.	2. Scirpus, sp.
3. *Betula alba*, L.	3. *Corylus Avellana*, L. (abundance of nuts). *Alnus glutinosa*, Gaetr.
...	

* The nomenclature of Hooker's *Student's Flora of the British Islands*, third edition, has been followed throughout.

The general sequence resembles that in the mosses at similar elevations in Kirkcudbrightshire examined last year (2), though in this case the upper forest zone of pine is wanting.

(2) *Eastern Region of the Basaltic Plateau.*

To the north-west of Portree stretches a wide expanse of peat some $3\frac{1}{2}$ miles in length by 2 miles in breadth, drained by the Lon an Eireannaich and a few tributary streams. Like the other lowland mosses of Skye, the surface of the moss is smooth and covered with a close mat of vegetation, the plants in greatest abundance being *Molinia cærulea*, Moench., *Scirpus cæspitosus*, L., *Eriophorum vaginatum*, L., stunted plants of *Calluna vulgaris*, Salisb., *Erica Tetralix*, L., abundant *Drosea intermedia*, Hayne, and Carices. The eastern part of the moss, lying nearer Portree, has been much dug for fuel, and for that reason the sections were made chiefly in the central and western region. Seen from the summit of some of the hills round Portree the moss appears as a large flat expanse, bounded on the north, south, and west by steeply rising hills, covered with Calluna, *Betula alba*, Pteris, and hill pasture.

The history of the peat over this district agrees in its main features with that described from the district round the Red Hills. The beds are as follows :—

1. Scirpus-Sphagnum peat, with traces of Calluna, 3–4 feet.
2. Eriophorum peat, containing abundant remains of Calluna, 3 feet.
3. Black hard dry peat, containing Scirpus remains and small twigs of *Betula alba*, 2 feet.
4. Clay, containing many small angular stones (basaltic).

These layers are not well defined : the upper portion of the peat contains very little Calluna or Eriophorum, but in bed 2, Scirpus and Sphagnum become less abundant, and *Eriophorum vaginatum* and Calluna increase in quantity. In the lower parts of zone 2, the peat becomes drier and Calluna increases greatly. The lowest layer—zone 3—does not contain any distinguishable plant remains, except small twigs and roots of *Betula alba*, L.

A series of sections taken near the banks of Dubh Lòn, however, showed a distinct basal layer of *Betula alba* of shrubby size. Associated with the birch are *Eriophorum vaginatum* (abundant), Carex, sp., *Narthecium ossifragum* (seeds abundant), *Calluna vulgaris*, and patches of Sphagnum, particularly near the base. The lower layers contain some sand and small angular stones (basaltic). Few of the birch stems are more than 4 inches in diameter, and the beds above the basal layer of birch agree in character with those already described in the first section. Several borings were taken towards the northern, southern, and western margins of the moss, and these all showed that the basal layer of shrubby birch extends generally over the area. The same feature can be well seen in many of the turbaries near Portree.

(3) *Western Region of the Basaltic Plateau.*

Peat is generally distributed over the moorland lying to the east of Loch Bracadale. The country here consists of small basaltic plateaux—the edges scarped to the depth of 12 or 15 feet, with the intervening small flat valleys thickly covered with peat. The basaltic terraces or plateaux are generally pasture-clad, whilst the intervening peaty areas are covered with a vegetation in which *Scirpus cæspitosus* is the dominant plant, with *Eriophorum vaginatum*, stunted *Calluna vulgaris*, *Erica Tetralix*, and *Drosera longifolia*.

The basal layer of the peat in this district, like that examined at other points in Skye, contains the remains of birch wood, and in no place does any bed of a different character occur below this.

A series of borings were taken just between An Cleireach and Mullach Glen Ullinish, at an elevation of about 130 feet above O.D., the depth of the peat varying here from 12 to 18 feet. All the borings showed a thick bed of *Betula alba* at the base of the peat, resting upon stiff blue clay, containing many small stones. A more detailed examination of the character of the peat was made by means of sections, and in all cases the sequence of the beds was as follows :—

1. Scirpus and Sphagnum peat, with slight traces of Calluna and *Erica Tetralix*, L.

2. Scirpus peat, with a considerable amount of *Phragmites communis*, Trin., and Equisetum, sp.

3. A well-defined layer of *Betula alba*, none of the branches exceeding 4 or 5 inches in diameter. In the upper part of this zone *Corylus Avellana*, L., is nearly as abundant as the birch, the nuts being exceedingly well preserved, but the lower layers contain only birch and *Alnus glutinosa*, Gaetr.

This basal woodland bed varies from 1 to as much as 6 or 7 feet in thickness. Attention might be called to the close agreement in sequence and general character between these beds and those described last year from the Kirkcudbrightshire mosses lying at 100–300 feet (3).

The peat over this district being generally deep and very wet, borings in many cases had to be resorted to. A large number were made through 14–30 feet of peat, and the same features were in every case observed—a thick basal layer of *Betula alba*, L., overlaid by the remains of moorland plants. Eight borings were taken from near the head of Osedale, at 250 feet above O.D., through 17 feet of peat, and a thick deposit of fine sand more than 9 feet in depth. The upper 2 inches of this deposit was greyish in colour, the material below this light yellow, and quite free from grit or stones. Several minute seeds, which, so far, have not been identified, were washed out of this material.

The several areas examined in Skye last year agree in all essential features. That the peat in North Uist also shows the same features is noteworthy, and in striking contrast to the history of the peat in the North-East Highlands.

The upper layers of birch are always mixed with abundance of *Corylus Avellana*, the wood, bark, and nuts being in an excellent state of preservation. When, however, the lower layers are examined, the wood in most cases has disappeared, and layers of birch bark are the only plant remains met with, imbedded in dry hard peat, which itself shows no distinguishable plant remains. In other words, there seems to be a break in continuity between the upper and lower layers of the same forest-bed. The same appearance has been noticed in North Uist. This feature may only mean that the lowest layers being dry and much compressed, the wood has shrunk and disintegrated, leaving only the bark to mark its former existence; or it may mean that after the lowest layer of the birch forest had been deposited a prolonged period of denudation set in, during which the birch stems were exposed to atmospheric agencies, thus causing the wood to disintegrate. This is a point which can only be solved by further observations on the Hebridean peat over large areas, but it may be remarked in passing that the feature is illustrated over areas in England where peat denudation is at present going on. In the Cross Fell district in Cumberland large areas of bare peat denuded down to the birch horizon occur, and the birch wood has frequently quite disintegrated, leaving only the bark intact. If birch wood again spread over such areas and the remains were sealed up in quickly forming peat, exactly the same features would be presented in a section as we find in the birch zone of Skye and Uist.

In the absence of any unmistakable datum line, it is impossible to correlate the layers in the Hebridean peat with those described from the Eastern Highlands and elsewhere. The general succession agrees closely with that in the lowland mosses in Kirkcudbrightshire, and the view that has perhaps most to recommend it is, that the basal birch forest of Skye and North Uist is contemporaneous with the lower forest of the Kirkcudbrightshire peat. If that reading be correct, the upper forest zone is wanting in Skye and North Uist, and its place is taken by beds of such plants as Scirpus, sp., Phragmites, Equisetum, Sphagnum, and Eriophorum. The absence of the upper forest-bed that has been observed by the author in several districts in the extreme north and west is interesting, as it may mean that the conditions suitable for the growth of forest on deep peat did not obtain over the areas of greater precipitation in the west; but the complete correlation of the beds from the Hebridean peat must be deferred until more areas in the Outer Isles and North-West Mainland have been investigated.

The North-West District of North Uist.

(One-inch Ordnance Survey—sheet 89.)—With the exception of small pasture areas, chiefly in the west, the whole of the island may be said to be peat-covered, and in many places the deposits appear to be of considerable depth. Sections were made chiefly in the Ben Aricaiter and Marrival district, but much of the southern and central parts of the island were walked over and the peat-hags examined for evidence on the characters of the upper zones of peat. Sections were first made on Sgurr nan Carrach

on Ben Aricaiter in the Valley district, at 180 feet above O.D. The peat is here only about 5 feet in depth, and the surface is channelled into peat-hags. The following beds were met with :—

1. Scirpus, Eriophorum, Sphagnum, and Racomitrium peat.
2. A thin layer containing abundant Phragmites.
3. Small *Betula alba*, L., none of the stems being more than 2 or 3 inches in diameter.
4. Black hard peat, separated distinctly from the overlying layer, and containing much compressed birch bark.

Borings were then made over an area of four or five square miles, lying at about the same altitude, and these showed the same sequence of beds. In all cases the same separation of the birch zone appeared, the upper containing well-preserved wood and the lower containing only birch bark.

Sections were also made on Ben Aricaiter and the moorland to the west, at altitudes ranging from 250–400 feet. The peat here is deeper, averaging about 9–12 feet, and shows the following :—

1. Scirpus, Eriophorum, Sphagnum, and Calluna peat.
2. Calluna becomes very abundant, and forms a zone some 3 or 4 inches in thickness.
3. Phragmites peat, with abundant *Menyanthes trifoliata*, L., towards the base.

This peat rests upon angular stones, micaceous sand, and coarse grit. Numerous horizontal bands of grey clay occur towards the base of the peat, with occasional patches of grit, showing that flooding was frequent during the deposition of these older beds.

Lower down, towards Loch Steaphain, *Betula alba* of fairly large size (10 inches to 18 inches diameter) is present at the same horizon in the peat as the Calluna zone described from the last section. This is the only evidence of the existence of an upper forest-bed met with in the Hebrides; but in the absence of any other well-marked datum line, the comparison of this peat with that in the Eastern Highlands cannot be made.

Caithness.

(One-inch Ordnance Survey—sheet 115.)—The stretch of country for some distance on each side of the Caithness-shire-Sutherlandshire boundary is, with the exception of a few small areas, entirely covered with deep peat deposits. The peat runs north-east into Caithness-shire, towards Thurso and Wick; and although, near these places, it has been much worked in past times for fuel, yet westwards and southwards it forms an almost unbroken covering on the flat moorlands and isolated hills like Ben Griam Mor and Ben Griam Beg. The area so covered may be put roughly at about 24 miles from north to south and 40 miles from east to west. It was found possible last year to touch only a small part of this area, the district chosen being westward from the Highland Railway between Altnabreac station and Scotscalder station. Although the

area investigated was small, yet it proved of interest, inasmuch as the peat there showed many of the features described from the Easter Ross and Inverness-shire districts.

The peat is developed on gently undulating moorland, and varies in depth from 5–12 feet.

The upper forest zone, commonly represented in other Highland districts by *Pinus sylvestris*, is absent over some part of this area, but makes its appearance in the eastern part of the district towards Morven and Ben Alisky. In some of the neighbouring districts, however, *Betula alba* takes the place of *Pinus sylvestris* as the dominant tree.

The first series of sections were taken at an altitude of 520 feet above O.D., and showed the following plant beds :—

Dominant Plant.	Accompanying Plants.
1. *Scirpus cæspitosus*, L.	1. Sphagnum, Calluna.
2. *Betula alba*, L. (trunks lying 30° S. of E.).	2. *Alnus glutinosa*, Gaertn., seeds of *Menyanthes trifoliata*, L. (abundant).
3. *Phalaris arundinacea*, L.	3. *Phragmites communis*, Trin.
4. Sandy peat, containing the remains of Equisetum, sp.	4. ...
5. Coarse sand and angular stones.	5. ...

Three other sections were made near Lochan nam Breac at about 600 feet. Here the following strata occurred :—

Dominant Plant.	Accompanying Plants.
1. Sphagnum.	1. *Erica Tetralix*, L., Scirpus, sp., *Calluna vulgaris*, L.
2. *Betula alba*, L.	2. *Alnus glutinosa*, Gaertn. *Menyanthes trifoliata*, L.
3. *Phalaris arundinacea*, L.	3. ...
4. *Salix Arbuscula*, L. A layer 18 ins. or 2 ft. in thickness, formed almost entirely of the stems of this plant.	4. *Potentilla Comarum*, Nestl. *Viola palustris*, L.
5. Drift, formed of closely packed small angular granitic and schistose stones, with the interstices filled with sand and grit.	5. ...

Another series of sections taken on the north and east of Cnoc Beul na Faire—a neighbouring hill, rising to 657 feet—showed the same sequence down to the base of the Betula zone,—but underlaid, not by *Salix Arbuscula*, but by moss peat. The remains were much decomposed, but apparently belonged to Polytrichum sp.

The history of the peat in this district is clearly shown by the sections just described. In some places the history of the peat goes so far back that the lowest layers contain the remains of a shrubby sub-arctic flora, represented by the *Salix Arbuscula* layer. Although this district only lies 400–500 feet above sea-level, it is interesting to find the same dwarf willow bed present here as in the Inverness-shire and Easter Ross districts lying at 1400–2000 feet, more particularly as *Salix Arbuscula* is now confined to rock ledges in the Highlands and a few districts in the Southern Uplands.

It is too early yet to say how far this layer extends over Caithness, but its occurrence near Altnabreac is of some interest, and further work may show that it extends over a

good part of the district. Its exact correlation with the beds in other districts must also be left until a greater area is examined in the surrounding district; but at present the sequence of beds in the upper peat would point to this sub-arctic bed of Caithness being contemporaneous with that of Coire Bog and the Inverness-shire watershed.

Easter Ross.

(One-inch Ordnance Survey—sheet 93.)—The main drainage of this district is carried by the River Carron on the north, the western slopes facing the Kyle of Sutherland and Dornoch Firth being drained by the smaller burns of A-na-h-Eigin, Wester Fearn and Easter Fearn Burn. The whole district consists of hilly country, almost entirely moorland, the average elevation being between 2000–3000 feet.

Glacial drift is widespread, and prominent moraines are well shown in many of the valleys at about 1250 feet.

The areas selected lie on the eastern slopes, along the upper course of the Abhuinn-a-Coire Bhuig and Allt Coire Bhenneit, two of the main tributaries of Wester Fearn Burn.

The peat is in a very denuded condition, forming high banks and gullies, which a number of small streams are continually cutting deeper. The average depth of the peat is about 8–12 feet over most of the area, and it lies in a broad basin, bounded by hills rising to about 2000 feet. This area lies amongst the hills, many miles away from any crofts, and has not been trenched upon for turbaries. Owing to the wasted character of the peat, it is possible to gain some idea of the general characters and sequence of the strata from an examination of the banks of the peat-hags. A useful datum line is apparent all over this area in the form of the upper forest zone, which can be seen projecting from the peat by all the stream and rill sides. Sections were first made at the western or upper end of the valley, at an altitude of about 1400 feet, and the following strata exposed :—

Dominant Plant.	Accompanying Plants.
1. Scirpus and Sphagnum, 3 ft.	1. ...
2. *Eriophorum vaginatum*, L., 18 ins.	2. Traces of Calluna in the upper layers.
3. *Empetrum nigrum*, L., 10 ins.	3. *Arctostaphylos alpina*, Spreng. (seeds very abundant).
4. Carex peat, very dry and hard, and readily separable into thin plates, 6 ins.	4. ...
5. *Betula nana*, L. (abundant), 6 ins.	5. ...
6. Fine grey sandy clay, slightly coloured with peat, 2 ins.	6. ...
7. Fine greyish white sand. No organic remains.	7. ...

Several other sections cut near by showed the same sequence. Sections were then made half a mile farther eastward, down the valley, at about 1250 feet. Here the sequence is as follows :—

Dominant Plant.	Accompanying Plants.
1. Recent peat, 2 ft.	1. ...
2. *Pinus sylvestris*, zone.	2. ...
3. Sphagnum, with traces of Calluna, 3 ft.	3. ...
4. *Betula alba*, zone of small size.	4. ...

Immediately below the Sphagnum, in layer (3), is a thin zone composed entirely of Calluna stems, and below that, next to Betula (4), is a layer consisting of Polytrichum stems and leaves. The Betula layer itself is traversed about midway by a layer of silty peat, containing remains of *Potentilla Comarum*, Nestl.

Dominant Plant.	Accompanying Plants.
5. Carices.	5. ...
6. *Empetrum nigrum*, L., 8 ins.	6. *Salix Arbuscula*, L.
7. Mossy peat, with silt containing many leaves of *Salix reticulata*, L., 6 ins.	7. ..
8. Angular boulders, with the interstices filled with angular granitic grit.	8 ...

Several sections were made near the one just described, at distances up to 100 yards; all presented the same features, and in all of them the Calluna and Polytrichum layers just above the Betula zone were well shown.

A fresh series of sections was taken further eastwards, and the sequence of beds was found to be essentially the same as that just described.

One section, for instance, showed the following strata :—

Dominant Plant.	Accompanying Plants.
1. Scirpus-Sphagnum, 3 ft.	1. ...
2. *Pinus sylvestris*, L.	2. ...
3. Sphagnum.	3. ...
4. *Pinus sylvestris*, L.	4. ...
5. Eriophorum.	5. Calluna (abundant in the upper layers of Eriophorum).
6. *Betula alba*, L.	6. *Menyanthes trifoliata*, L. *Eriophorum vaginatum*, L.
7. *Empetrum nigrum*, L.	7. Eriophorum, Polytrichum.
8. *Salix Arbuscula*, L.	8. *Betula nana*, L. (abundant in the upper layers). *Dryas octopetala*, L. *Potentilla Comarum*, Nestl. (abundant in the lower layers).
9. Sand.	9. ...
10. Closely packed stones.	10. ...

These three series of sections, taken at different points, agree closely in general characters, although, as might be expected, there are small differences in the character of the peat at the same horizons in the several sections.

The earliest vegetation that took possession of the land on the passing away of the glaciers consisted of Arctic willows, such as *Salix reticulata* and *Dryas octopetala*, L.; these were quickly followed by a close growth of other creeping willows, such as *Salix Arbuscula*, L., mixed with a good deal of *Potentilla Comarum*, Nestl., and some *Empetrum nigrum*, L., and *Arctostaphylos alpina*, Spreng. When the upper part of the Salix bed is reached, *Betula nana*, L., becomes abundant, mixed with quantities of Empetrum stems and seeds. So abundant is the Empetrum that where the streams have cut down to the base of the peat, the wiry stems can be traced all along the peat-hags, standing out from the sides as a fringe of bleached twigs,—presenting very much the same features as the author recorded from the Merrick Hills peat in Galloway (3).

The dominance of *Dryas octopetala*, *Salix reticulata*, *S. Arbuscula*, with *Betula*

nana, *Arctostaphylos alpina*, and *Empetrum nigrum*, gives a decidedly Arctic aspect to these basal layers and indicates much severer conditions than obtained during the deposition of the peat immediately above, which is chiefly formed of *Betula alba*. Above the Arctic beds the vegetation then gradually underwent a change,—the Salix, hitherto so dominant, disappeared, and the ground became entirely covered with Empetrum mixed with Eriophorum,—*Arctostaphylos alpina*, Spreng., still lingering on, although sparingly. After some 18 inches of peat, formed almost entirely of the stems of Empetrum, had been deposited, a complete change of conditions and vegetation took place. The Empetrum died away and a growth of *Betula alba* of small size—most of the stems being less than 8 inches in diameter—covered the whole district and persisted until a thickness of 2 or 3 feet of Betula remains had accumulated. The lower layers of the birch zone contains quantities of the seeds of *Menyanthes trifoliata*, L., this plant having first made its appearance in the upper layers of Empetrum. Above this no further Betula remains are met with, but the peat—at that time some 5 feet in depth—became tenanted with Eriophorum, mixed with a good deal of Calluna. This wet moorland vegetation persisted until 2 feet of peat had been deposited and was succeeded by a great growth of almost pure Calluna, representing much drier conditions. This represents the beginning of the upper forest zone, for the Calluna moor quickly became covered with *Pinus sylvestris*, which attained a large size.

Referring to the sections which have been given, it will be seen that in section 3 two distinct pine zones are represented, separated by 1–3 feet of Sphagnum peat. This is a feature found very generally over Coire Bog and in other Highland areas and its possible significance will be considered in detail in the section dealing with the Spey-Findhorn watershed and in the summary and general conclusion at the end of this paper. As the upper forest zone of pine passed away, the character of the peat indicates wetter and possibly colder conditions, as it is formed entirely from the remains of Scirpus sp., Eriophorum, and Sphagnum. A considerable period appears to have elapsed between the passing away of the upper forest zone and the incoming of the present type of vegetation, as quite 2 feet of Scirpus-Sphagnum-Eriophorum peat lies upon the pine zone and it is not until about 1 foot below the present surface that the plants of the present vegetation begin to make their appearance in abundance.

From the evidence obtained, it seems that the peat began to grow over this area soon after the ice which deposited the large moraines at about 1000 feet had retreated, —first under arctic or sub-arctic conditions, merging into wet moorland conditions, changing to dry forest conditions, and then relapsing to wet moorland, with a gradual change to present conditions. The correlation of these successive strata with those in other districts and with the later phases of the glacial period will be considered in the part of the paper dealing with the Spey-Findhorn area and in the general summary.

The Spey-Findhorn Watershed.

(One-inch Ordnance Survey—sheet 74.)—This area lies in the north-east of Inverness-shire, and north-east of the Highland Railway, between Carrbridge and Tomatin. The watershed—which here separates the two rivers by about 8 miles—lies at an average elevation of 1800 feet to 2100 feet and is really a north-eastern continuation of the Monadleath Mountains, being only separated from that range by the Slochd Mor, a narrow valley which descends to 1300 feet. The watershed is formed by a series or chain of rounded hills, whose flanks and summits are thickly covered by peat, which in most places has been subjected to considerable denudation. These hills at the present day are covered with a vegetation in which Calluna is the dominant plant, mixed with a small amount of *Arctostaphylos Uva-ursi*, *Vaccinium Vitis-Ideaa*, *V. Myrtillus*, Carices, *Nardus stricta*, and *Eriophorum vaginatum*. The peat over most of the hills above 1800 feet has an average depth of 11–13 feet, and the upper forest zone, lying about 3½ feet below the present surface of the peat, forms a useful datum line over the whole area. Most of the sections made in this district lay about the 2000-feet contour line, and a striking agreement was shown, not only in the sequence of the strata over this watershed, but also with the history of the peat on the Findhorn-Nairn watershed and Coire Bog in Easter Ross.

Three typical sections are selected from the many that were made, to illustrate the general history of the peat over this area.

Section I., 1800 feet on the north side of Allt na Feithe Sheillach :—

Dominant Plant.	Accompanying Plants.
1. Recent peat.	1. ...
2. *Pinus sylvestris*, L.	2. ...
3. Sphagnum.	3. ...
4. *Pinus sylvestris*, L.	4. Calluna (abundant).
5. Sphagnum.	5. Eriophorum, Calluna (traces towards the base).
6. *Betula alba*, L. (fairly large shrubby trees).	6. ...
7. *Empetrum nigrum*, L.	7. Eriophorum sp., *Menyanthes trifoliata*, L., *Polytrichum juniperinum*, and in the lower layers abundant *Betula nana*, L.
8. *Salix Arbuscula*, L.	8. *Lychnis alpina*, L., *Potentilla Comarum*, Nestl., Carex sp., *Viola palustris*, L., *Munim pseudopunctatum*.
9. *Salix reticulata*, L. *S. herbacea*, L., leaves.	9. *Veronica alpina*, L.
10. Stone pavement.	10. ...

Section II. :—

Dominant Plant	Accompanying Plants.
1. Recent peat.	1. ...
2. *Pinus sylvestris*, L.	2. ...
3. *Sphagnum*.	3. ...
4. *Pinus sylvestris*, L.	4. ...
5. *Betula alba*.	5. *Menyanthes trifoliata*, L.
6. *Empetrum nigrum*, L. A close layer about 18 ins. deep of stems mixed with seeds of this plant.	6. Eriophorum sp. (traces of *Betula nana* abundant towards the base).
7. *Salix Arbuscula*, L.	7. *Potentilla Comarum*, Nestl., Carex sp., *Menyanthes trifoliata*, L.
8. Stone pavement.	8. ...

SECTION III. :—

DOMINANT PLANT.

1. Recent peat.
2. *Pinus sylvestris*, L.
3. Sphagnum peat.
4. *Betula alba*, L.
5. Glacial deposits.

It will be seen that Sections I. and II. show almost exactly the same sequence of plant remains. The basal beds differ, however, in the two cases.

The history of events in Section I. appears to have been as follows:—After the passing away of the glaciers which occupied the Highland valleys, the first vegetation clothing the barren summits and flanks of these hills was essentially Arctic in character, consisting in some places of a close growth of *S. reticulata* with *S. herbacea*, together with such Arctic-Alpine plants as *Lychnis alpina*, *Veronica alpina*. This early growth of an Arctic flora did not cover the whole ground, for it is absent from many of the sections taken on the same watershed. It appears to have formed patches of vegetation on the otherwise bare ground, in much the same way as is found at the present day on high northern tundras. In describing the high northern tundras of Taimyr, MIDDENDORFF (4) speaks of the oases of Arctic vegetation amidst the general barren desert. On the more southerly tundras, however, larger areas are occupied by vegetation than are left unoccupied. The Arctic willows at the base of these mosses represent the first condition; the overlying sub-Arctic willow, with the accompanying set of plants, represent later sub-arctic conditions. In this district the peat evidently began to form very soon after the passing away of the glaciers and a complete record of the sequence of vegetation is preserved. That the conditions were still severe during the formation of the *Salix Arbuscula* zone may be inferred from the abundance of this willow over many miles, together with the appearance of many seeds of *Arctostaphylos alpina*, *Lychnis alpina*, and patches of *Mnium pseudo-punctatum*. The same story is told by the Empetrum zone lying immediately above. The dominance of Empetrum is very marked here. When pieces of peat from this zone are split open, patches of peat 3 or 4 inches across are sometimes entirely covered with the seeds of this plant. In other places patches covered with the seeds of *Arctostaphylos alpina* are frequent. In the field, this zone is easily recognisable by the abundance of the stems of Empetrum. Over this district, then, three distinct zones are found at the base of the peat, each having its dominant or characteristic plant. The lowest or oldest zone represents high northern tundra conditions; the second, cold conditions, but not unlike those at present prevailing over the southern region of Greenland; and the third zone represents a still further amelioration of the climate, for at the base of the third zone *Betula nana* is abundant, whilst the upper part contains no remains of that plant.

In the peat lying above these three zones no sign of a return to an Arctic or sub-Arctic flora has been recognised, and none of the plants occurring in the lower Arctic zones are met with. The resemblances of some of these basal beds to plant formations

at present existing in Greenland will be discussed in the general summary and conclusion.

As the Empetrum period passed away, the ground became covered with shrubby *Betula alba*, which forms a continuous and well-marked layer in the peat of this area. The white birch is accompanied by such plants as *Menyanthes trifoliata* (abundant), (which also occurs in the Empetrum zone, and very sparingly in the *Salix Arbuscula* zone), Eriophorum, and traces of *Calluna vulgaris*. This birch zone cannot be correlated with the lower forest zone met with in the Merrick-Kells mosses and in the Tweedsmuir peat of the Southern Uplands (3). The position occupied by the peat and the sequence of the beds above and below the birch zone point to its being a growth of small birch at the beginning of a wet moorland period. Sphagnum and Eriophorum are abundant in this zone, and temperate woodland plants noted in the lower forest zone in the Southern Uplands are wanting (3).

At the same time the wide occurrence of a shrubby growth of birch above the basal Arctic and sub-Arctic beds over the present watershed, the Findhorn-Nairn watershed, in Coire Bog and in Caithness, suggests that we are not dealing with a local phenomenon, but with a feature which characterised large areas at the same time. All the evidence, however, shows that the Betula zone here belongs to the wet moorland period which succeeded the primitive Arctic and sub-Arctic conditions. The early occurrence of woodland over these mosses would at first sight seem to imply that a considerable interval must have elapsed after the deposition of the basal Arctic vegetation and before the appearance of the birch. At the time the basal beds began their growth any large area of birch could hardly have existed within several degrees of latitude—if one can judge from the present state of things in Greenland—but only 1 foot or $1\frac{1}{2}$ feet above this Arctic vegetation we find widespread areas covered with small *Betula alba*. It must be remembered, however, that we are dealing only with deep peat areas, and in the passage from Arctic through sub-Arctic to temperate conditions these areas would tend to lag behind the drier non-peat covered land. For the cold, water-logged character of the peat would favour the retention of a northern type of vegetation, while it would at the same time exclude many incoming plants of more southernly range, which would otherwise have competed with those already growing over the peat areas. Thus, on the peat-covered tracts, a sub-Arctic type of vegetation might possibly have flourished contemporaneously with the growth of a northern type of woodland over the non-peat-covered lands at a similar elevation. This may explain the invasion of the peat at such an early stage by woodland. It must also be borne in mind that the non-existence of trees over the peat mosses at any one period does not prove that woodland may not have existed elsewhere. All one can say in this connection is, that at one particular time the whole peat areas of Scotland were treeless and covered with a type of wet moorland vegetation and at another time they were wholly covered with forest. It can hardly be questioned that the first represents wet insular conditions; and the last, drier, warmer, Continental

conditions. In connection with the spread of birch over this area, it might be pointed out that the Arctic plant bed at the base of this peat represents a very late phase of the glacial epoch.

When these Arctic plants flourished the period of maximum glaciation had long passed away, and a mild, interglacial epoch had been followed by a partial return to glacial conditions in the Southern Uplands and to severer glaciation in the Highlands. Thereafter mild interglacial conditions had again supervened, only to be succeeded by a relapse to cold conditions, with tundras in the South of Scotland and local glaciation in the Highlands. It was during the passing away of the latter period that the Arctic plants now under consideration spread over the district. When the last ice-sheet had disappeared and was succeeded by a mild interglacial climate, Britain became joined to the Continent and the immigration of our present flora took place. The later return to cold conditions marked by the Mecklenburgian or Fourth glacial stage did not result in the appearance of a general ice-sheet, but produced only glaciation in the north of Britain and over hilly or mountainous ground. These later stages then probably did not destroy any species of the British flora, but only modified its distribution. The Mecklenburgian stage would result in a driving of temperate plants to the southern parts of Britain, with a corresponding southward extension of Arctic plants. The Lower Turbarian would likewise permit of a southward extension of the present Arctic members of the flora, only less marked than the last; whilst the Upper Turbarian or Sixth glacial stage was so slight that it would scarcely cause any change in the distribution of the flora except over ground lying at considerable elevation in the north. The greater part of the British flora, then, immigrated during the interglacial period following on the disappearance of the last ice-sheet, and its subsequent history has been one long series of changes as regards distribution. The explanation of the present distribution of the British Flora must be sought for not only in respect to the present climatic conditions and soil characters, but also in regard to the constant "shuffling" which has been caused by climatic changes during the later phases of the glacial epoch. In other words, the present broad distribution of the flora is the resultant of both historical and ecological factors; and in considering the broad distribution of the flora as a whole over Britain, the historical factor may be the more important of the two. A simple instance of this is the absence of some members of the British flora from Ireland. These plants are not excluded from Ireland through any inability to thrive there, but from their failure to immigrate during the last land connection with Britain. In the same way, the present grouping of certain plant associations in Britain may have been influenced by the great changes in distribution which took place during the Fifth glacial stage, when Arctic plants formed a close covering over low ground in the Southern Uplands of Scotland; and again during the succeeding forest period (upper forest zone), when some of the wettest peat mosses were covered with pine forest and Calluna, and plant associations characteristic of bog or swamp conditions were driven to the far West.

The upper forest zone in this district consists of an upper and lower layer of *Pinus sylvestris*, separated by about $1\frac{1}{2}$ feet of Sphagnum peat. This doubling of the pine zone has now been noticed in several distinct areas in the North of Scotland; it is a constant feature over Coire Bog in Easter Ross, on the Findhorn-Nairn watershed and over large areas in the fifty miles of country lying between Tongue on the north and Lairg in the south. Both the upper and lower layer of pine are similar in character—both contain abundant remains of Calluna, whilst the intervening peat is formed of Sphagnum, with scarcely any trace of Calluna or other plants. If this feature was only developed over small areas and in patches it might well be due to local alterations in drainage and the formation of small boggy pools in the pine forest, but its widespread character does not lend any support to this view. Two possible explanations occur: (*a*) either the lower layer of pine exhausted the food supply in the peat, decayed, and was buried by a layer of Sphagnum, the regenerated moss being again covered with pine in the manner described by GUNNAR ANDERSSON in reference to the Swedish moors; or (*b*) the alternation of pine, Sphagnum and pine may indicate some climatic change. Were the former view correct we might have expected to find that some of the large areas in Southern Scotland where the pine zone is well represented would show the same feature. So far, however, the duplication of the upper forest zone is confined to districts in the North of Scotland. For this reason the author suggests that the phenomena may be due to some climatic change. Following the formation of the upper forest zone, there seems to have been a recurrence of cold conditions, just sufficient to produce small glaciers in corries lying above 3000 feet. Whilst this small glaciation of the highest ground in Britain would not change the distribution of the flora over the lower-lying parts of the country, it must have resulted in a greater precipitation, and tended to restrict the forest areas—particularly over the peat mosses. This change would be more marked in the North and West, and must have decreased rapidly towards the South and the lowland tracts. In this view the lower layer of the upper forest zone would represent the upper forest zone of the Southern Uplands,—the overlying Sphagnum beds would indicate the general character of the peat-moss flora during the corrie-glacier period; while the upper layer of pine above the Sphagnum beds would represent drier conditions occurring some time after the passing away of the cold phase. The cause of the second invasion of the peat mosses in the Highlands by pine forest, and their non-invasion in the Southern Uplands after the corrie-glacier period, might point to *Pinus sylvestris* having at this period died out in the South. At the present day, as is well known, no forests of *Pinus sylvestris* are native in Southern Britain, primitive pine forest being almost restricted to the area north of the Forth. This condition of things may date from the upper forest-bed. That the period following immediately after the corrie-glacier period was not characterised by great precipitation is supported by the fact that the mosses resting on the 25-feet raised beach contain much *Corylus Avellana* and *Betula alba*. Reading the upper layer of pine as post-corrie-glacial, that bed would be contemporaneous with the Corylus and Betula layer of the 25-feet raised

beaches. The peat over this area then shows a definite succession of changes. Beginning its growth under Arctic conditions, its flora gradually changed to sub-Arctic, and later to a northern type of woodland. After a period of northern woodland, pronounced wet moorland conditions supervened and continued for a lengthy period, until at last the whole area became covered with a forest of *Pinus sylvestris*. As this decayed its place was taken by Sphagnum. After this a second pine forest appeared, and later wet moorland conditions again supervened, and continued until the present type of flora spread over the ground, which is of a distinctly drier type than that it has replaced. The sequence of plant strata over the present area so closely agrees with that seen in the peat of the Findhorn-Nairn watershed, that the changes referred to have more than a local significance.

The Findhorn-Nairn Watershed.

(One inch Ordnance Survey—sheet 84.)—This district lies on the border between Inverness-shire and Nairnshire. The watershed, which runs north-east and south-west, consists of smooth rounded hills rising to an elevation of 1500 feet to 2000 feet, and in general topographical characters is similar to the Findhorn-Spey watershed lying to the south-east. The hills, however, are more rounded and the summits are flatter. After the field work for the Spey-Findhorn watershed had been completed, observations were carried on over this area, with the view of comparing the history of the peat in the two districts. Sections were taken chiefly on the watershed lying between Beinn Bhuidhe Mhor, Carn nan tri tighearnan, and Carn a' Mhais Leathain. The peat between these three summits has been much denuded, and the upper forest zone (pine) can be traced along the sides of the peat-hags. Section I. was taken near the head of Dalreoch Burn, at about 1250 feet, and showed the following strata :—

Dominant Plants.	Accompanying Plants.
1. Sphagnum.	1. *Calluna vulgaris* (scarce). Scirpus, sp. (abundant).
...	
2. *Pinus sylvestris*, L.	2. *Calluna vulgaris*, L. (fairly plentiful).
3. Sphagnum.	3. ...
4. *Pinus sylvestris*, L.	4. *Calluna vulgaris* (very abundant).
5. Eriophorum and Sphagnum.	5. ...
6. *Betula alba*, L.	6. Sphagnum and Eriophorum. *Menyanthes trifoliata*, L.
7. *Empetrum nigrum*, L.	7. *Viola palustris*, L., *Arctostaphylos alpina*, Spreng.
8. *Salix Arbuscula*, L.	8. *Empetrum nigrum*, L. (traces).
9. Closely packed angular stones, with clay below containing large boulders.	9. ...

Some six sections were taken in all, which showed the same succession of dominant plants. Other sections taken lower down showed that the birch zone rested directly upon the glacial deposits, the older beds being absent. This absence of the lower beds frequently occurs in different districts, and simply means that the peat in those places had begun to grow at a later date. It is important to notice, however, that in such cases these newer beds always show the same sequence as we find in places where the

whole post-glacial history of the peat is represented in the plant strata. This is strong evidence that the alternation of Sphagnum or Eriophorum beds with forest zones in the upper layers of the peat is due, not to edaphic factors, but to climate. If the alternation of the plant remains in the upper peat were due to soil conditions, the sequence of the upper beds would scarcely be the same whether they rest almost directly upon drift and a few inches of peat or upon some 3 feet of peat.

The history of the peat over the present district is of interest, inasmuch as it is in striking agreement with the general history of the peat lying upon the Spey-Findhorn watershed. The oldest layer, represented in some places on the latter watershed by *Salix reticulata* and *S. herbacea*, appears to be wanting, but the dominant plants in the eight superposed beds are the same. At the base of the moss *Salix Arbuscula* again forms a thick bed of peat, mingled with traces of Empetrum. Coming 6 inches higher in the peat the remains of Salix die out, and its place is taken by Empetrum, which again forms a dense layer of the same character as that met with in Coire Bog and elsewhere in the Highlands, mixed with capsules of *Viola palustris* and seeds of *Arctostaphylos alpina*. A layer of Eriophorum-Sphagnum peat overlies the *Betula alba* zone, which itself contains abundant remains of these plants. The wood at the base of the Betula zone is of much smaller size than that near the top, although abundant remains of Eriophorum and Sphagnum occur throughout; further, there is no sharp break between the Betula and Sphagnum and Eriophorum layers—one merges gradually into the other. There is every indication that both these layers belong to the same condition of things, the moorland having gradually changed from somewhat cold conditions (shown by the stunted character of the birch and the close annual rings) to a state of things when the growth of Sphagnum and Eriophorum became too rapid to permit the further growth of birch.

Coming into the upper forest-bed, we meet with that duplication of this bed which is so common over the Highland areas. The possible explanation of this phenomenon has already been discussed when dealing with the Spey-Findhorn watershed. It is probable that the districts which are still to be examined in North-West Sutherland and Ross may furnish more direct evidence with regard to this problem.

Summary and General Conclusions.

The peat deposits described in this paper may conveniently be divided into two groups:—

1. Those occurring in the Western districts, possessing no Arctic plants at the base, but a basal forest-bed, overlaid by a considerable thickness of plant remains, indicative of wet moorland conditions.

2. Those in the North and North-East Highlands, possessing only one well-marked forest-bed, and with an Arctic plant bed at the base of the peat.

The peat examined in Southern and Central Skye and North Uist falls under the former head, and may be considered first.

The abundance of *Betula alba* and *Corylus Avellana* at the base of this peat and resting upon the glacial deposits, is clear evidence that all this peat began to form under temperate or genial conditions. No trace of Arctic plants has hitherto been found either at the base or elsewhere in the Hebridean peat, thus showing that there is a break of continuity between the glacial deposits and the peat that rests upon them. This gap will probably be bridged by deposits yet to be found in other parts of the Hebrides, but at present its existence deprives us of a useful datum line for determining the age of this peat. The character of the basal layers of the peat would seem to indicate more genial and dryer conditions than presently obtain; for the greater part of Skye and North Uist (about 75 per cent. in one and 90 per cent. in the other) now covered with peat was clothed with thick woods of birch and hazel, with some alder. Such a type of vegetation is hardly represented in the islands at the present day. Allowance must, however, be made for the fact that when this woodland period existed the peat was extremely thin and presumably better drained than now. Immediately above the woodland bed a decided change in the general flora is observed. Birch, hazel, and alder become replaced by thick beds of Sphagnum, Phragmites, Digraphis, Equisetum, Sphagnum, and Scirpus. Only one sign of any change in conditions is given in these deep beds of marsh and moorland peat—at a depth of 3–5 feet from the present surface the remains of *Calluna vulgaris* become very abundant. This feature, however, is so inconstant—appearing in some districts and disappearing in others—that not much reliance can be placed upon it.

The one feature that stands out distinctly from an examination of this peat is the absence of Arctic plants and the constant presence of temperate forest remains at the base, overlaid by marsh and bog peat. The question arises—Can the forest-bed here be correlated with the lower buried forest described from the Southern Uplands? If so, it is difficult to account for the absence of the intercalated Arctic plants above the lower forest-bed. The cause that induced the growth of Arctic plants in the Southern Uplands after the dying out of the lower forest could scarcely have failed to affect the Hebrides also. At the same time, it must be remembered that the Hebridean peat lies at a low elevation near the sea, on flat or gently sloping ground, and far away from any elevation exceeding 300 or 400 feet. It would thus tend to retain the features of a marsh vegetation through any cold period characterised by great precipitation. The climatic conditions that introduced an Arctic flora to the Southern Uplands would certainly bring about local glaciation in such a mountain group as the Cullins, but the districts under discussion would be well outside the range of the glaciers.

The great similarity of these peat deposits to those in Kirkcudbrightshire (3) is noteworthy. In that district a basal birch and hazel forest exists, probably contemporaneous with that of the Merrick-Kells and of the Tweedsmuir mosses, whilst the Arctic bed of those districts is represented by thick beds of Phragmites in Kirkcudbrightshire. If—as seems probable—the birch forest of the Hebrides is contemporaneous with the lower buried forest of the lowland peat in Kirkcudbrightshire, then the upper

buried forest of the South of Scotland is wanting in the Hebrides, and its place is taken by beds indicating moist insular conditions. This is what might be expected,—for dry Continental (forest) conditions in the South and East of Britain would hardly extend to those outlying portions in the West which were fully exposed to the influence of the Atlantic. We should then have the interesting fact that, during a dry forest period when the peat mosses over the greater part of Britain became clothed with pine and Calluna, the type of flora associated with wet insular conditions continued to find a refuge in the extreme West—only to flow out eastwards again on the destruction of the forests and the resumption of insular conditions over Britain.

The peat coming under the second heading has, so far, only been found in the Eastern and Northern Highlands. The evidence here is much more conclusive, owing to the presence of two well-marked datum lines. In Inverness-shire on the Spey-Findhorn watershed, at about 2000 feet, the series of events can be clearly traced, and direct comparison made with the peat described from the South of Scotland (3).

The peat here began to grow under Arctic conditions soon after the deposition of the glacial deposits upon which it rests. Arctic willows (*Salix reticulata* and *S. herbacea*) are dominant in the basal layers, gradually changing to a type of flora indicative of sub-Arctic conditions (*Salix Arbuscula*, *Betula nana*, *Empetrum nigrum*, *Potentilla Comarum*, etc.). After that, the flora changed; the moors hitherto covered with shrubby sub-Arctic plants now bore a close growth of Eriophorum and Sphagnum, amongst which a shrubby growth of birch managed to find a footing. The humid conditions apparently became more pronounced, as the birch presently disappeared, and vegetation was represented only by Sphagnum. Thereafter, Sphagnum ceased to flourish, and a forest of pine with an undergrowth of Calluna overspread the peat. Gunnar Andersson (5) has described the causes which, on some of the Swedish peat mosses, lead to the alternation of forest formations and Sphagnum beds. According to this author, tree growth does not persist for any length of time upon Sphagnum remains, the organic nutriment which has collected on the surface being soon exhausted, so that the forest is weakened and invaded by a new growth of Sphagnum. Layer upon layer of this plant is formed, until the land becomes so dry that heath formations appear and contribute to further decomposition, paving the way for a new forest growth. The replacement of Sphagnum by pine forest in the Scottish areas does not bear evidence of having been caused by such changes in the food contents of the peat, seeing that this upper forest of pine is, with one or two exceptions, always present in the peat, whether it lies on steeply sloping or level ground, either at high or low elevations. Further, the upper forest zone always occurs at the same horizon in the peat, and gives place again to Sphagnum and Scirpus beds, which have persisted down to the present time. If the phenomenon was due to the causes described by Gunnar Andersson, one would expect to find different districts showing different alternations—some more and others less frequent changes from Sphagnum moor to woodland. As it is, districts so widely separated as Caithness-shire, Inverness-shire, and Galloway show

the same sequence in the upper layers,—first Sphagnum moor, then pine forest, changing to Sphagnum, Eriophorum, and Scirpus moors, which last persist down to the present time. The impression given by these deposits rather suggests the occurrence of a dry genial period during the deposition of the younger peat-beds, due to secular changes in conditions which must have affected the whole of North-West Europe.

The general sequence of events on the Spey-Findhorn watershed is illustrative of what happened in other districts in Inverness-shire, East Ross-shire, and Caithness-shire. The peat in all these districts tells the same story: it begins its history under Arctic conditions, which later change to sub-Arctic, continues its growth under a milder but much more humid climate, ceases to form whilst clad with thick forests of pine, and again continues to grow down to the present time under the influence of a moister insular climate.

The type of Arctic vegetation found at the bases of these mosses may be briefly compared with some of the plant formations described by WARMING (1) from Greenland. The general facies of the vegetation which occurs in the "oseraies" bears some resemblance to the vegetation over many of the Scottish areas during the *Salix Arbuscula* period. In Greenland, however, the typical willow is *Salix glauca*, L., which from 67°–68° lat. grows to the height of about 2 metres, whilst further north, in about 73° lat., its height does not generally exceed ·5 metre. The soil is formed of a black humus, with occasional copses on the dryer ground. Herbaceous plants, amongst which are *Veronica alpina*, *Viola palustris*, Carices, and Equisetaceæ, occur abundantly. Mosses are plentiful, whilst lichens are few in number. This agrees very closely with the general character of the Salix beds near the base of the Scottish peat,—willow is always dominant, along with many mosses, particularly Hypnaceæ and *Minum pseudo-punctatum*, together with the seeds of herbaceous plants, some of the species being the same as those mentioned by WARMING.

The Correlation of the Peat Beds with the later stages of the Glacial Period.

As the question of glacial and interglacial stages has been referred to several times in this paper, it is perhaps desirable to add a general statement of the glacial succession and compare briefly the corresponding strata found in the peat.

All the peat deposits examined are post-glacial in the sense that they are of later date than the epoch of district ice-sheets and mountain-valley glaciers. The peat, however, contains evidence that subsequent to its earliest growth cold conditions again supervened, shown by the series in the Southern Uplands, where a widespread buried forest occurs at the base, formed of *Betula alba*, *Corylus Avellana*, along with such plants as *Ajuga reptans* and *Epilobium palustre*, L., and overlaid by thick Sphagnum beds, above which comes an Arctic bed of *Salix reticulata*, *S. herbacea*, *Loiseleuria procumbens*, and *Empetrum nigrum*. There can hardly be any doubt that here we are dealing with climatic changes of an extensive character, and that conditions capable of inducing such an Arctic growth at 1000 feet in the extreme South-West of Scotland must

have caused considerable glaciation in the northern and mountainous districts. That this cold stage was separated from the preceding glacial stage by a considerable period is shown conclusively by the existence of the thick lower forest zone and overlying Sphagnum beds. This forest zone has been found in all the older peat hitherto examined in the South, its widespread character and thickness indicating a clear break between the glacial deposits on which this peat rests and the intercalated Arctic plant bed above. As the cold conditions which resulted in the extension of the local ice-sheets and valley glaciers of the Southern Uplands (Fourth glacial stage) passed away an Arctic flora would linger on over these upland valleys and hills—it may be for a considerable time,—but nothing except a decided climatic change could bring such a flora back again after the whole of the South of Scotland had become clothed with temperate forest. The existence of these intercalated Arctic plant beds in the Southern Uplands therefore strongly supports the view, already established from the geological evidence—that the Mecklenburgian or Fourth glacial stage, whose glaciers deposited the prominent sets of moraines at a general level of 900–1200 feet in so many of the Southern Upland valleys, was followed by a genial interglacial period, represented by the lower buried forest of birch and hazel, with accompanying temperate plants. This gradually came to an end, its passing away being chronicled in the peat by thick beds of Sphagnum, representing wet and cold conditions,—and was succeeded by Arctic conditions, during which an Arctic flora flowed downwards and southwards from the high northern ground to which it had been forced during the genial lower forest period, and covered all the lower ground of the South of Scotland.

The evidence afforded by the peat in those districts which have been examined in the Highlands is no less conclusive.

All the deposits examined at high elevations and in the extreme North begin their history at a stage later than those at low elevations in the South. In the northern deposits the lower forest bed, with the overlying Sphagnum beds, is entirely wanting; on the other hand, all the upper beds of the Southern Uplands, from the intercalated Arctic zone to the present surface of the peat, find their representatives in the Highland peat. These Highland deposits began to form at the passing away of the cold conditions which gave rise to the intercalated Arctic bed of the Southern Uplands; in other words, the Arctic plants in the Southern Uplands represent the whole of the Fifth glacial episode, whilst the basal Arctic bed in the Highlands represents the passing away of that phase. That milder conditions again supervened after this stage is shown by the existence of the upper forest-bed in all the Eastern and Northern Highland districts,—this corresponding with the upper forest zone of the Southern Uplands. It is interesting to note that *Betula alba* is the dominant tree in the lower buried forest, whilst *Pinus sylvestris* is always dominant in the upper buried forest. This may not indicate any decided difference in the climate during the two forest periods, but it does indicate a considerable break between the two periods.

It is perhaps too soon to attempt the complete correlation of these different strata

with those described by workers in Scandinavia and Germany, but some points of resemblance may be briefly indicated.

In Western Norway the peat shows considerable resemblance to that described in Kirkcudbrightshire (2). According to BLYTH (7), two forest-beds can be distinguished, —an upper, consisting chiefly of *Pinus sylvestris*, and a lower, of Quercus with *Corylus Avellana*. These two forest-beds are separated by about 6 feet of peat in a much compressed condition. The chief difference here is the dominance of birch in the lower forest-bed of Scotland and of the oak in that of Norway. In both cases, however, we have a lower and upper forest-bed, separated by moorland and swamp peat of considerable thickness.

GUNNAR ANDERSSON (6) has traced out the history of the peat in Southern Sweden in a very complete manner and finds that an Arctic flora is nearly always present at the base, consisting of such plants as *Dryas octopetala*, *Salix polaris*, *S. herbacea*, *S. reticulata*, *Oxyria Digyna*, *Arctostaphylos alpina*, etc. After this a definite succession of forest-beds can be made out,—first birch, then in succession spruce, oak, and pine. This peat is post-glacial in the sense that it was laid down after the disappearance of the Great Baltic glacier and appears to have originated about the same time as the *Yoldia* clays of the Baltic area. According to the geological evidence, the great Baltic glacier appears to have been contemporaneous with the district ice-sheets and mountain-valley glaciers of Scotland, as pointed out by GEIKIE (8). If that is so, the birch forest of Southern Sweden would be contemporaneous with the lower buried forest of the Southern Uplands, the Arctic flora below this being missing in the Scottish areas. At the same time the evidence of the Scottish areas of a later return to cold conditions is apparently wanting in Southern Sweden, for no Arctic plants are mentioned by GUNNAR ANDERSSON as occurring above the birch forest remains. But the complete correlation of the British peat strata with those occurring on the Continent is a task which is hardly possible with the amount of evidence that is at present available, and much further work requires to be done before the comparison can be made with safety. It only remains to point out the great similarity which exists between the basal Arctic beds in the Scottish Highlands and those in Scandinavia. Dryas appears to have been more abundant in the Scandinavian areas, but in both countries we find Arctic willows predominating in the basal peat layers with such plants as *Arctostaphylos alpina*, *Betula nana*, L., and *Empetrum nigrum*, L. NATHORST (9) has described such an Arctic flora as represented in many districts in Norway, GUNNAR ANDERSSON (6) describes the same from Southern Sweden, and STEENSTRUP (10) has given many instances where such plants form a distinct zone in the fresh-water clays underlying the oldest peat mosses in Denmark. Indeed, such deposits have been described not only from Scandinavia, but also from Russia and Northern Germany. Reference might also be made to the interesting paper by WILLE (11), giving an account of the changes in distribution of an Arctic flora in Norway, and to another by the same author (12) dealing with the distribution of *Dryas octopetala* in post-glacial times.

The exact correlation of the deposits belonging to widely separated areas depends upon the presence in each area of one or two well-marked datum lines, for a basal layer of Arctic plants in one country can hardly be correlated with a basal layer of Arctic plants in another without good evidence of the contemporaneity of the glacial deposits upon which they rest.

In conclusion, I wish to express my thanks to Dr HORNE, F.R.S., for much valuable help and advice during the progress of the work and for the use of many of the Geological Survey maps dealing with the districts mentioned in this paper; and to Professor GEIKIE, LL.D., F.R.S., for many suggestions.

I am also much indebted to Professor TRAIL, M.D., F.R.S., for determining some of the willows.

The scientific expenses of this investigation have been defrayed by a grant from the Government Grant Committee of the Royal Society.

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EXPLANATION OF FIGURES.

Fig. 1. General view of one of the lateral valleys leading out of Osedale, W. Skye. The small flat-topped basaltic hills are generally pasture-clad, whilst the intervening valleys are covered with *Scirpus cæspitosus*, *Calluna vulgaris*, Eriophorum, etc. The peat varies in depth from 8 to 30 feet, and is described on page 339.

Fig. 2. General view of the Coire Bog district. Mounds of *Rhacomitrium lanuginosum* (shown in the photograph) are numerous. The peat varies in depth from 6 to 18 feet, and is described on page 343.

Fig. 3. Peat from the *Salix Arbuscula* layer, Coire Bog, Easter Ross. A block of peat split in half in a horizontal direction, and the fresh surface photographed, page 344.

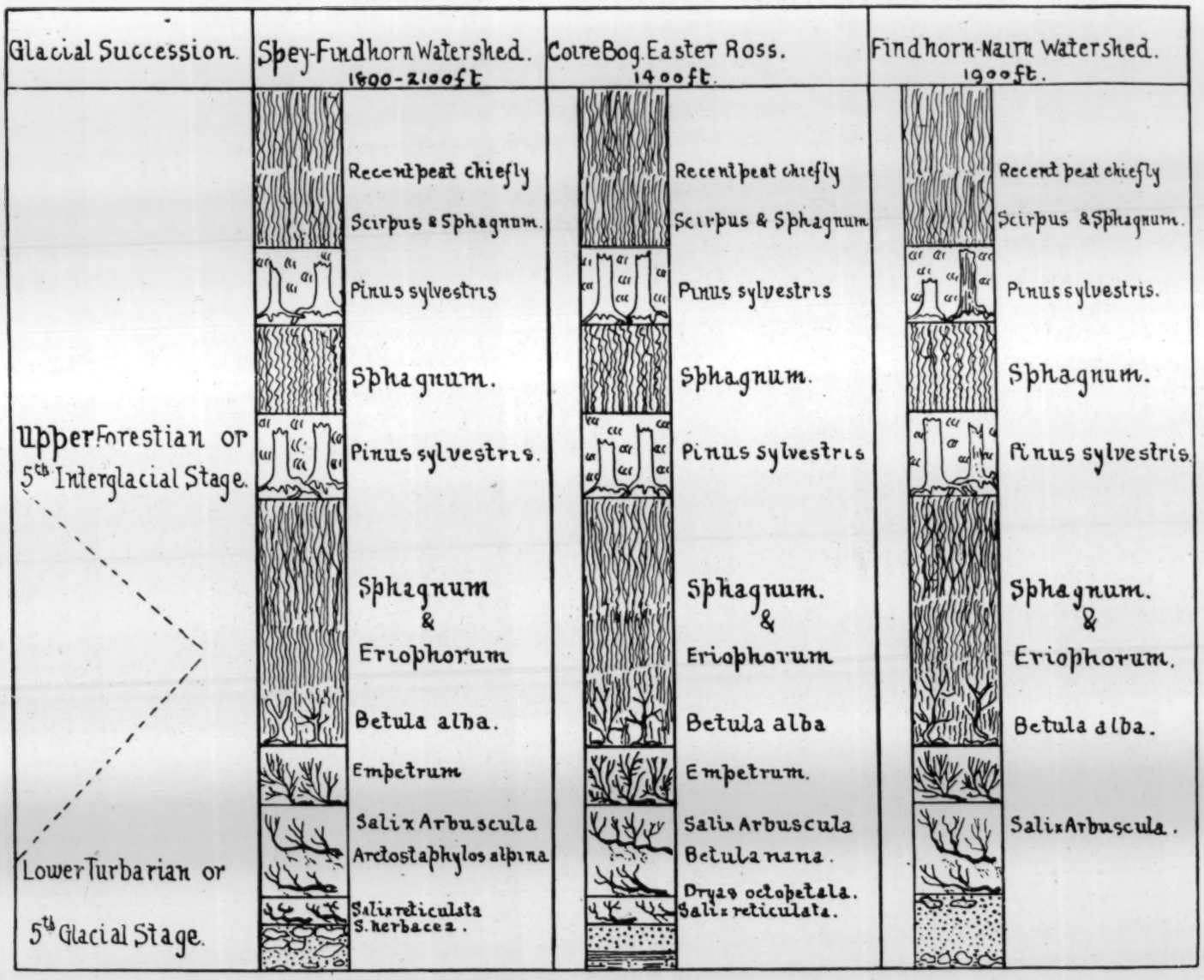
Fig. 4. *Pinus sylvestris*. Base of trunk with roots projecting from a bank of peat. The trees here rest upon a thin bed of Sphagnum, which in turn rests upon glacial deposits,—the older beds yielding the remains of an Arctic flora found elsewhere in the district being absent in this spot. Coire Bog, Easter Ross. Page 345.

Fig. 5. Peat from the *Salix Arbuscula* layer. The block of peat has been split in half in a horizontal direction and the willow stems photographed *in situ*. Spey-Findhorn watershed. Page 347.

Fig. 6. Peat from the Empetrum layer. The upper part of the photograph shows Empetrum stems, whilst the lower half shows Sphagnum lying immediately over the Empetrum layer. Spey-Findhorn watershed. Page 347.

Fig. 7. *Pinus sylvestris* layer. The side of a bank of peat has been cut back and two pine layers exposed, separated by 3 feet of Sphagnum peat. Findhorn-Nairn watershed. Page 352.

Fig. 8. Empetrum, *Betula nana*, and *Salix Arbuscula* layers projecting from the base of a bank of peat, resting upon glacial deposits. Findhorn-Nairn watershed. Page 352.



Succession of Peat Strata in the North-East Highlands.

LEWIS: Plant Remains in the Scottish Peat Mosses. Part II.—PLATE I.

FIG. 1.

FIG. 2.

LEWIS: Plant Remains in the Scottish Peat Mosses. Part II.—PLATE II.

FIG. 3

FIG. 4.

LEWIS: Plant Remains in the Scottish Peat Mosses. Part II.—PLATE III.

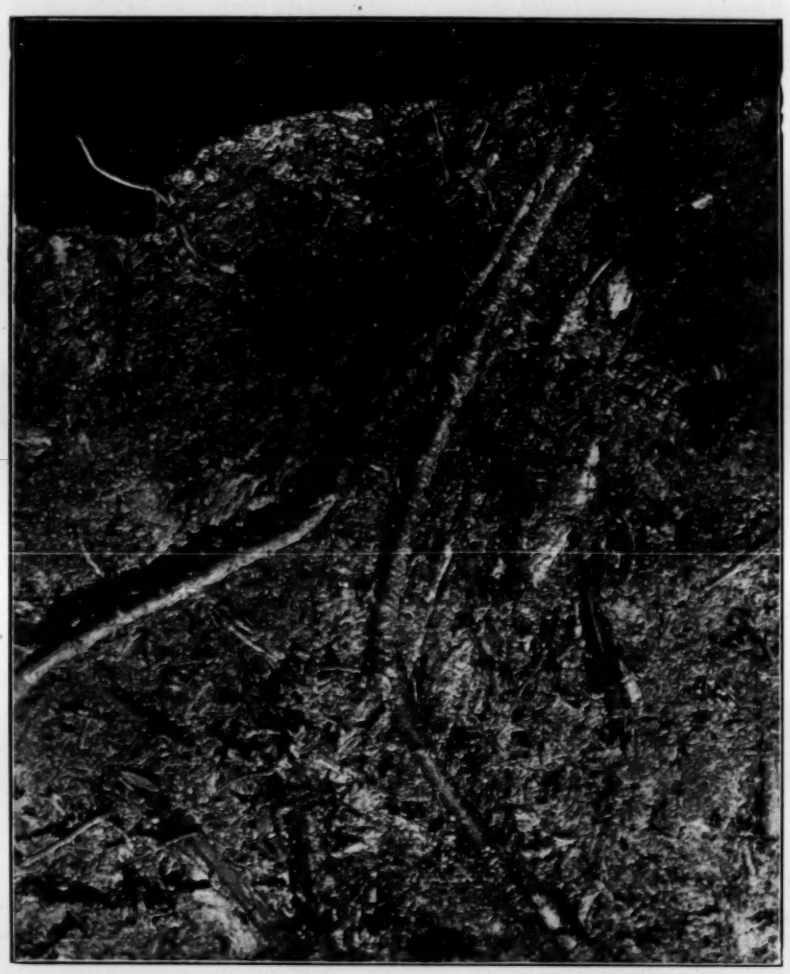


FIG. 5.

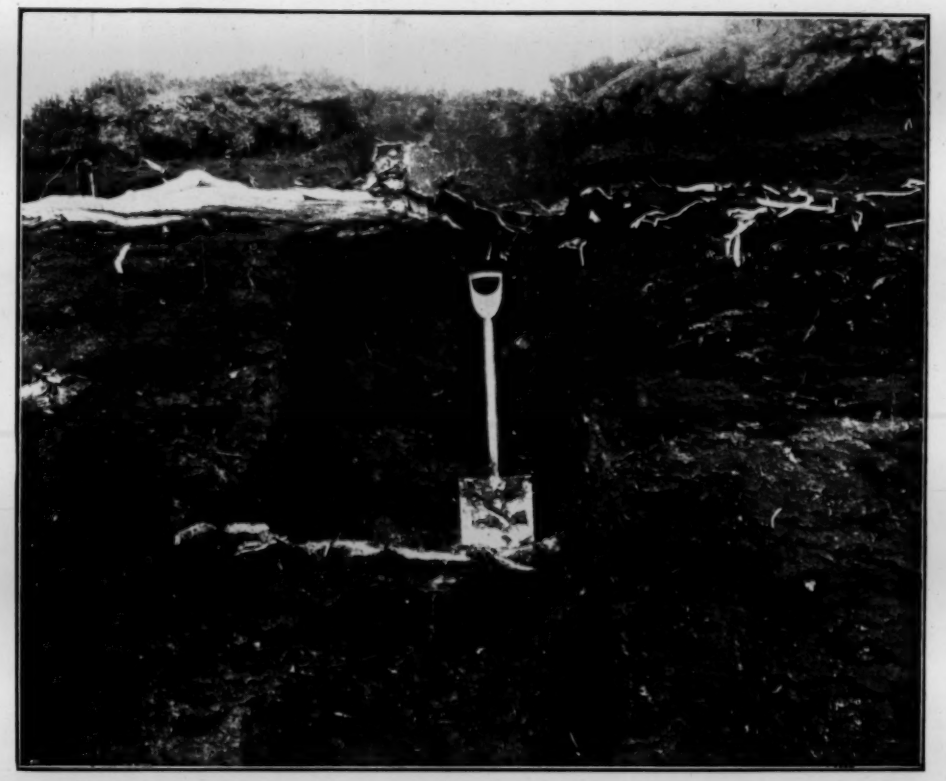


FIG. 7.

LEWIS: Plant Remains in the Scottish Peat Mosses. Part II.—PLATE IV.

FIG. 6.

FIG. 8.

XIV.—An Investigation of the Seiches of Loch Earn by the Scottish Lake Survey.

Part I.: **Limnographic Instruments and Methods of Observation.** By **Professor G. Chrystal.**—Part II.: **Preliminary Limnographic Observations on Loch Earn.** By **James Murray.** *Communicated by* Professor CHRYSTAL.

(MS. received July 16, 1906. Read July 16, 1906. Issued separately October 17, 1906.)

PART I.

In this communication some account is given of the various instruments used in the survey of the seiches of Loch Earn, of the methods of observing, and of the reduction of the results of observation.

In Part II., which immediately follows, Mr JAMES MURRAY gives an account of the preliminary survey, of which he had charge. Later, a summary will be submitted to the Society of the results as regards the periods and nodes of the lake; and finally, an account will be rendered of the observations made in order to connect the occurrence of seiches with other atmospheric phenomena.

THE DIRECT-ACTION WAGGON RECORDER LIMNOGRAPH.

From certain peculiarities in the limnograms obtained on Loch Ness and Loch Treig, it was suspected that the Sarasin limnographs in the possession of the Lake Survey might not be sufficiently sensitive to record faithfully the seiches of small amplitude which Mr WEDDERBURN'S preliminary observations had led us to expect on Loch Earn. Also it was desired, if possible, to work three limnographs simultaneously—one near the uninode, one near the binode, and one at one of the ends of the lake. I therefore designed a new limnograph, intended so far as possible to avoid the principal defects which had been noticed in the Sarasin instruments during the somewhat rough usage which they had experienced in Loch Ness, but more particularly on Treig, where firm installation and effective shelter was difficult to attain. The defects in question were mainly three:—(1) Multiplicity of connections and gearing from which it proved impossible permanently to eliminate back-lash; (2) Friction of sliding parts; (3) Difficulty of adjusting the recording pen so as to avoid shake, blotting and tearing of the paper, and clogging of the pen.

The design adopted was a modification of the band transmission of PLANTAMOUR'S limnograph.

Fig. 1 gives a general view of the instrument. A steel band 2·31 m. (7 feet 7·4 inches) long, 6 mm. broad, and ·14 mm. thick—which was, in fact, a Chesterman's steel tape—is attached to the float, passes over two identical carefully bushed pulleys, each of which has a diameter of 7 cm. and a flat rim 6 mm. broad. The band is weighted by a counterpoise at its free end. To the horizontal part of the band is fastened, by means of a screw clamp, a small waggon, whose horizontal motion is to be the same as the vertical motion of the float. To secure geometrically accurate

Fig. 1.

horizontal motion of the waggon with as little friction and sticking as possible, it is arranged to run on two horizontal rails, about 3·6 cm. apart. On one side of the waggon are two small wheels (diameter about 2 cm.), each having a V-groove, the sides of which are slightly convex. These two wheels run on a rail which has a wedge-shaped edge. On the other side of the waggon is another small wheel with a flat or slightly convex rim, which runs on a flat rail. If care be taken to adjust the band correctly on the pulleys before tightening the waggon clamp, it will have no tendency to leave the pulleys; lateral guides, except as a precaution against accident, are unnecessary, and thus one source of friction is avoided. It is necessary that the waggon

wheels be well centred and run easily; also, the waggon should have sufficient weight, and be adjusted at a proper height to prevent tendency in any of the wheels to rise from the rail, owing to the pull of the band. The recorder used was one of the shorter varieties of the common stylographic pen. The pen was carried by a split tube, hinged on a horizontal axis pivoted in two conical bearings, one of which was mounted on a spring of sufficient strength to take up any looseness and prevent all possibility of shake. Usually the weight of the pen itself tilting round the axis gave sufficient pressure on the paper; but this pressure could be adjusted by pushing the pen backwards and forwards through the split tube, or, if necessary, by using a counterpoise. There are, of course, limits to the angle at which the pen writes satisfactorily. Between the two pulleys and close to them are two vertical plates, each having a small slot through which the band passes; these limit the motion of the waggon, so that the pen cannot pass off the paper. The waggon and pen are shifted backwards and forwards, as the mean level of the lake requires, by means of the screw clamp; and the graduations on the Chesterman's tape enable us to keep a record of the height of the water by merely reading off the graduations at the edge of the clamp.

The rest of the apparatus closely follows the Sarasin instrument. There is a removable stock-drum for holding the roll of unused paper, on which I found it an improvement to put a small friction brake; this gives a more uniform tension to the paper, and steadies the clock by giving it more uniform work to do—as the variation of the pull, owing to the variation of the diameter of the roll of paper, can be made a small fraction of the pull due to the brake. From the stock-drum the paper passes over a guide-drum, then over a horizontal writing-table, then between the two draw-rollers, the lower of which is driven by the clock; and is finally delivered freely into the bottom of the box which contains the limnograph. A store roller is added on the delivery side, on which the paper delivered is rolled up from time to time, and kept until it is convenient to remove it from the instrument.

As in Sarasin's limnograph, a time-marker is fixed at the end of the writing-table. This consists of a stylograph mounted exactly like the recording pen, except that it is attached to a plate which can rotate about a vertical pin. This plate when at rest is kept in contact with a fixed stud by a tension spring; but once every hour a cam carried by the arbor of the driving clock causes the plate to jig a little round its axle-pin, so that the straight line drawn by the time-pen shows a small V-shaped indenture. These indentures are useful for counting hours; but for accurate time we relied on a series of time-marks made once or twice a day or oftener by giving the band of the limnograph a slight pull, so that the recording pen made a line across the limnogram. Opposite this line the date and time of day were marked on the paper. No attempt was made to regulate the driving clock, which was left alone as much as possible, the only demand made upon it being uniformity of driving.

The driving rollers were made of solid gun-metal; they were slightly hollowed out in the middle, and grip the paper merely between slightly roughened portions at

the ends. The weight of the upper roller is ·79 kg. ($1\frac{3}{4}$ lb.). As my instrument was intended in the first instance to go at one speed only (approximately 1 mm. per minute), the lower or actual driving roller was geared to the clock by means of a fork on the clock arbor and a cross-piece on the axle of the roller.

The clock itself was an excellent piece of old work, presented to us by Professor Macgregor from the spare apparatus in the Physical Laboratory, and fitted with an escapement by Mr Ritchie, Edinburgh.

The float was a hollow zinc cylinder about 4 cm. high, having a diameter of about 25 cm., and loaded so as to weigh about 2·27 kgs. (5 lbs.). The weight of the counterpoise was ·68 kg. ($1\frac{1}{2}$ lb.). It was found during the preliminary tests of the apparatus that a certain load on the float was necessary to secure that the waggon should answer promptly to a slow *fall* of the water-level. There was some difference of opinion regarding the exact reason for this; but there is no doubt about the fact.*

The well used was a cylinder 6 feet long of $13\frac{1}{2}$ inches (34·3 cm.) diameter, with a short access tube of $1\frac{1}{2}$ inch (2·8 cm.) diameter at the bottom, and a side-door at the top, which gave access to the band in order to make time-marks, and for other purposes.

The paper used was 9·75 inches (24·8 cm.) broad. In order to avoid blotting and the accumulation of fluff, a kind having a somewhat smoother surface than the Geneva paper was generally used with the stylographs. The ink employed was a mixture of 3 parts of Judson's mauve† dye, 4 parts of glycerine, and 12 parts of water. One filling of the pen lasted for several weeks; and, once fairly started, the pen wrote for several days without attention. All that was required was to clear the point occasionally from dirt and fluff gathered from the paper. The style should not project too far; and its point should be ground as smooth as possible, so as not to cut or plough up the paper. The pen should allow the ink to run freely so that it even blots at first. After a little the blotting ceases, and the pen settles down to draw a strong and fairly thick line. If the line gets very fine, this is an indication that the style is getting clogged; and the point should then be cleaned. In order that the pen may work well, the limnograph box must not be left open too much; otherwise the wind drys the slowly delivered ink too quickly, and the style clogs; or, if the air is moist, the paper gets sodden, and the pen blots and may tear the paper.

The construction of the apparatus was ably carried out by Mr A. H. Baird of Edinburgh, and worked admirably during the two months that it was under my charge at St Fillans. This was very creditable to the maker, considering that there was very little time for preliminary tests, and none for subsequent modification.

In fig. 2 the instrument is shown in its box, which is placed within the little

* The apparent anomaly may have been due to capillary action on the zinc float. In the fixed limnographs of Forel and Plantamour, the float was surrounded by a band of cloth, so as to be constantly wetted by the water. In my instrument as used on Loch Earn, this precaution was not taken.

† Red would have been much better for subsequent photographic reproduction of the limnograms.

house built for it by Mr JAMES MURRAY. Unfortunately the body of the observer conceals the well cylinder, and the vertical box which encloses the counterpoise.

To give an idea of the results obtained by the instrument, tracings (scale $\frac{3}{4}$) of four portions of the limnogram are given in figs. 3, 4, 5, 6. The indented time-line is omitted, except in fig. 6. Near the middle of fig. 3 will be seen the time-mark across the limnogram. The absence of any break or discontinuity in the trace shows that the pen returned exactly to the same point on the paper after the band had been pulled. This furnishes a very important test that the apparatus was sensitive

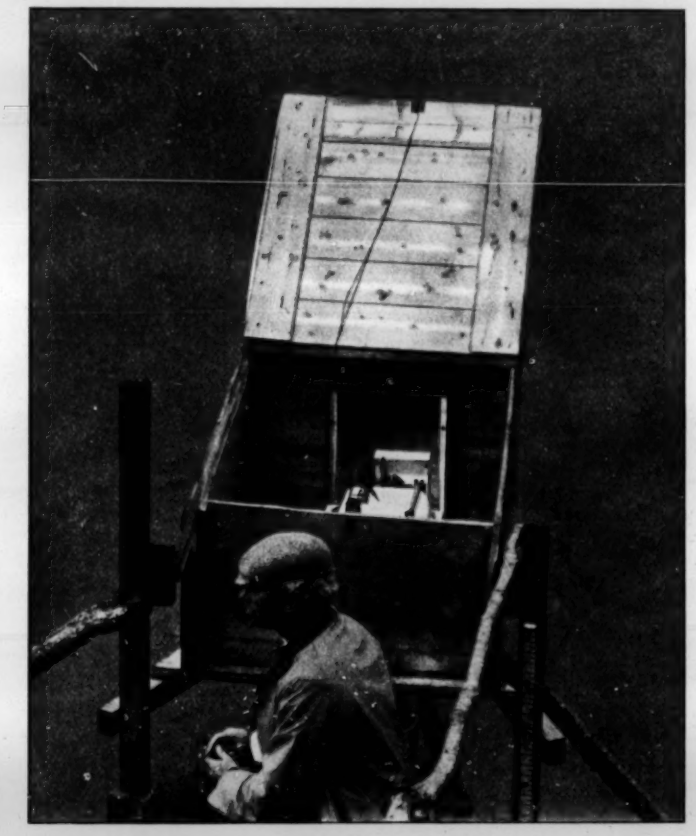


FIG. 2.

and in good working order. Our Sarasin instruments in their original form would not stand this test.

ADAPTATION OF THE SARASIN LIMNOGRAPH.

It was found very easy and not very expensive to adapt the Sarasin limnographs to the model above described. All the external gear was removed. The travelling recording bar and its driving pulley were taken away, and a pair of rails fitted to carry an improved form of recording waggon, which is figured in Mr MURRAY's paper on the "Preliminary Observations on Loch Earn."* Instead of the band a piece of sounding wire was used, which was passed over the two pulleys which had carried the travelling

* Part II. of this series.

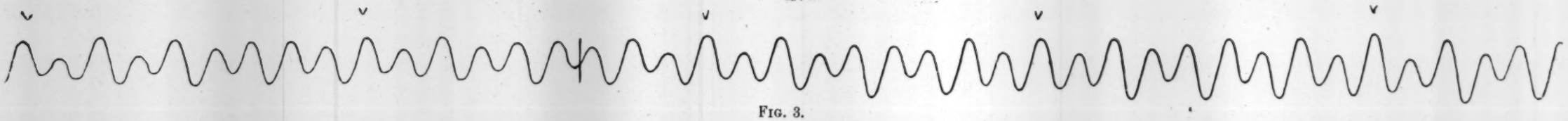


FIG. 3.

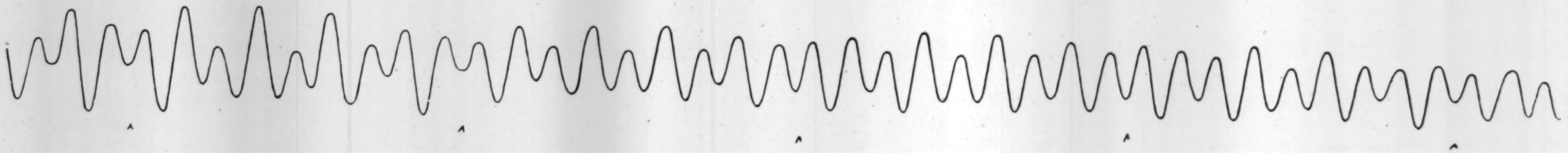


FIG. 4.

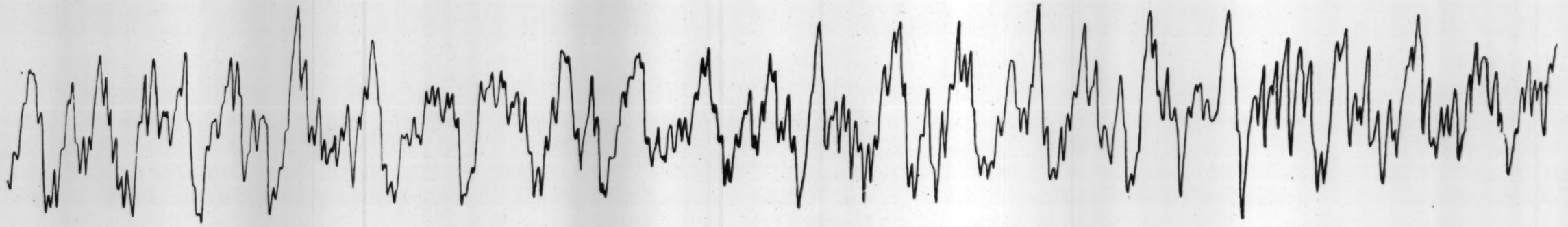


FIG. 5.

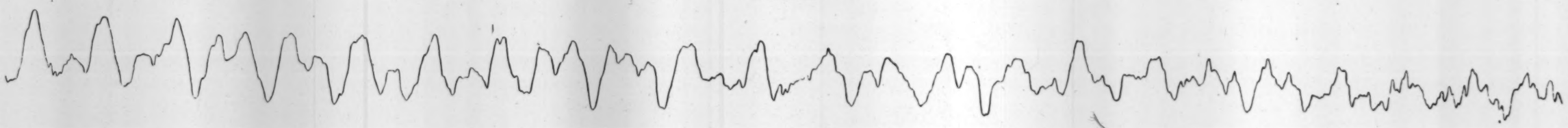


FIG. 6.

FIG. 7.

bar. All that was necessary was to turn two shallow grooves in the rims of these pulleys to keep the wire in position.* The recording waggon was arranged at such a height that the wire could be clamped to it, exactly as the band is clamped in my own model. The Sarasin thus modified worked perfectly, and is a very compact and fairly portable instrument.

Fig. 7 is a tracing of a limnogram furnished by this instrument running at its high speed (2·977 mm. per minute). The scale is $\frac{3}{4}$. As the limnograph was placed near the eastern binode, the trace is nearly sinusoidal; but shows well-marked embroidery, as the weather was not calm.

The Statolimnograph.

In studying the vibrations of Loch Earn, that is the denivellations, generally of very small range, whose period of fluctuation is a minute or less, the want was felt of a self-registering limnograph, as sensitive as our Endrös index limnographs (which

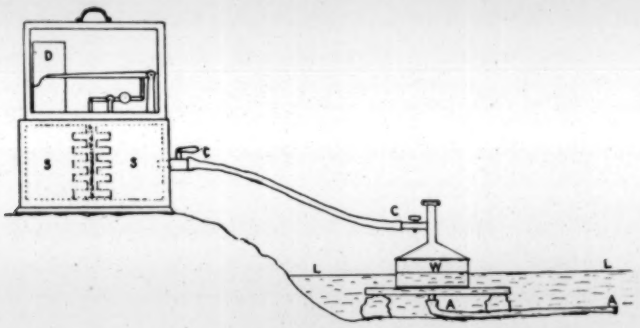


Fig. 8.

multiply about four times), and having an equally open time-scale. This want was supplied by utilising a Richard statoscope, which had been put at our disposal by the Lake Survey, originally for the purpose of studying sudden changes of the barometric pressure in connection with seiches.

The nature of the statoscope will be understood from fig. 8, where it stands on the left. It consists essentially of a cylinder, S S, communicating with the outer air by a stop-cock C. Into this cylinder is let a set of aneroid capsules of the usual construction, except that they are not sealed up but open; so that the interior communicates freely with the outer air. A rod fixed to the bottom of the set of capsules is jointed to the end of a system of multiplying levers, which work a recording pen, exactly as in the ordinary barograph. The time-scale of the recording drum is about 5·3 mm. to the minute. When the stop-cock C is open, the pressure inside and outside the capsules is the same, and the pen remains at zero. When C is closed and the air in the cylinder isolated, then, supposing the temperature inside to remain constant, the displacement of the pen at any time is proportional to the difference between the atmospheric pressure at that time and the atmospheric pressure at the time when C

* If preferred, a steel band could be used, by turning the rims of the two pulleys flat.

was closed. In the advertisement of the instrument it is said that for a difference of 1 mm. of mercury the pen shows a displacement of 25 mm. In our instrument this displacement was nearer 20 mm.; but this may have been due to a repair which was necessary after the return of the *Antarctica*, on board of which the instrument had been used for observations on ocean waves. In order to minimise the variation of temperature, the cylinder S S is packed with non-conducting material. Nevertheless, the temperature does vary slowly; and this must be attended to in using the instrument.

The statoscope is converted into a statolimnograph by the arrangement shown in fig. 8. W is a closed well with tubes fitted at the top and bottom. To the bottom tube is attached an india-rubber access tube similar to that used with an ordinary index limnograph. The tube at the top of the well is fitted with a screw vent-plug, by means of which the pressure inside W can be made equal to the atmospheric pressure at will. By means of a branch from the top tube, and a connecting tube C C, the well is put in communication with the cylinder of the statoscope, the stop-cock C being, of course, open.

When a limnogram is to be taken, the well is placed on a board with a hole in it to let the lower tube pass through. This board is supported on stones, so that the access tube, A A, passes freely under it, and the water stands about half-way up the inside of the well, the vent-plug being, of course, open, and the level outside and inside W the same. The vent-plug is then closed; and the rise and fall of the lake level causes a corresponding rise and fall inside W, which compresses or rarifies the confined air, thus causing proportional differences of pressure between the outside and inside of the capsules. These differences are registered by the recording pen, and thus we get a limnogram. When the apparatus is working as a limnograph it is not affected by small variations of the barometric pressure—as these take effect equally within the capsules and at the lake level, from which they are transmitted through the well to the inside of the cylinder, *i.e.* to the outside of the capsules. A considerable change of the barometric pressure during an observation would, of course, alter the mean level in the well and thus affect the mean volume of the confined air, which would slightly alter the sensitiveness of the instrument. It is obvious that the larger the diameter of the well and the smaller the volume of confined air (in W, C C, and S S), the greater will be the change of internal pressure for a given rise of the lake level. We shall consider the theory more in detail later on.

The statolimnograph was found to work admirably, and gave traces of great variety and interest. A few specimens are given in figs. 9–12; the significance of the results obtained will be explained in a later communication.

The arrangement of the apparatus in actual use is seen in fig. 13, where it is seen between the observer and the boat, partly on shore and partly in the lake.

Alternate Use of the Statoscope as a Limnograph and Barograph.—In order to convert the arrangement above described into a very sensitive barograph, we have merely to shut the stop-cock C. The instrument then proceeds to register the

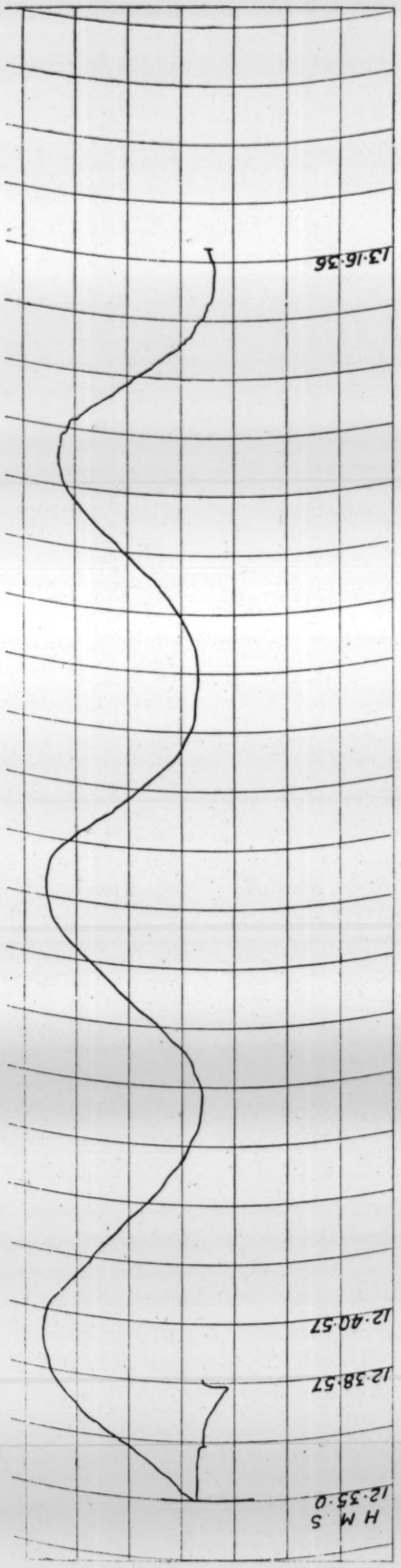

13·16·36
12·40·57
12·38·57
H M S
12·35·0

FIG. 9.

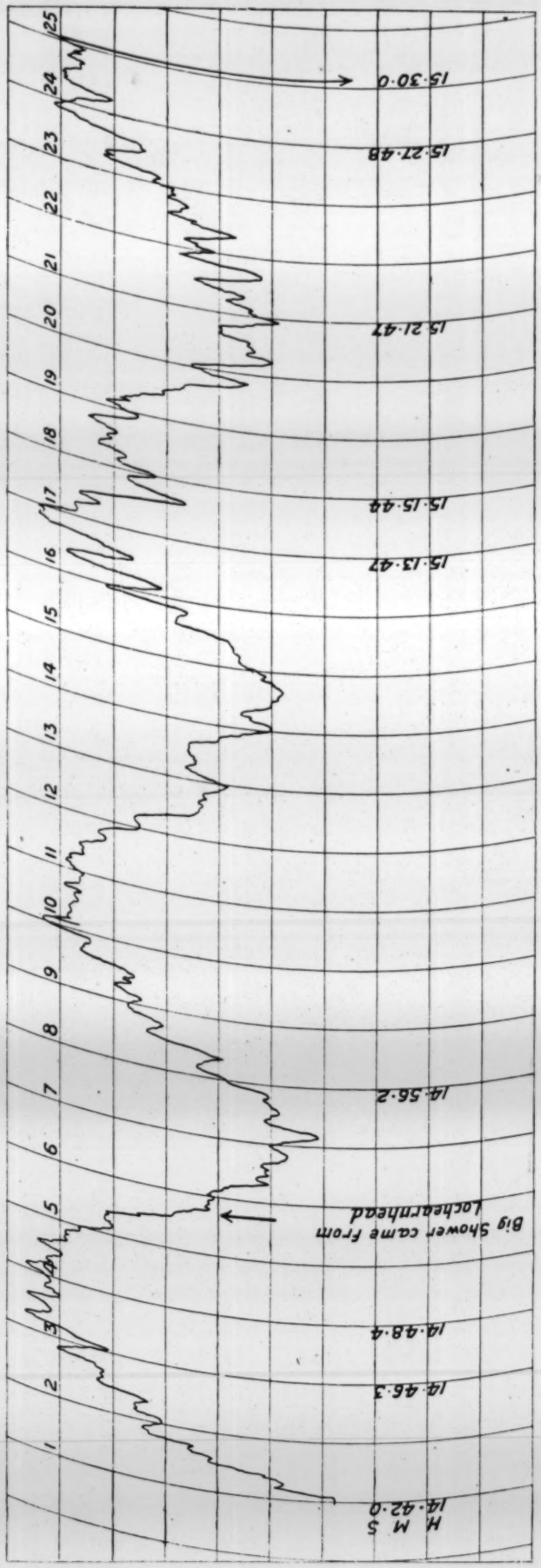

15·30·0
15·27·48
15·21·47
15·15·44
15·13·47
14·56·2
Big Shower came from Lochearnhead
14·48·4
14·46·3
H M S
14·42·0

FIG. 10.

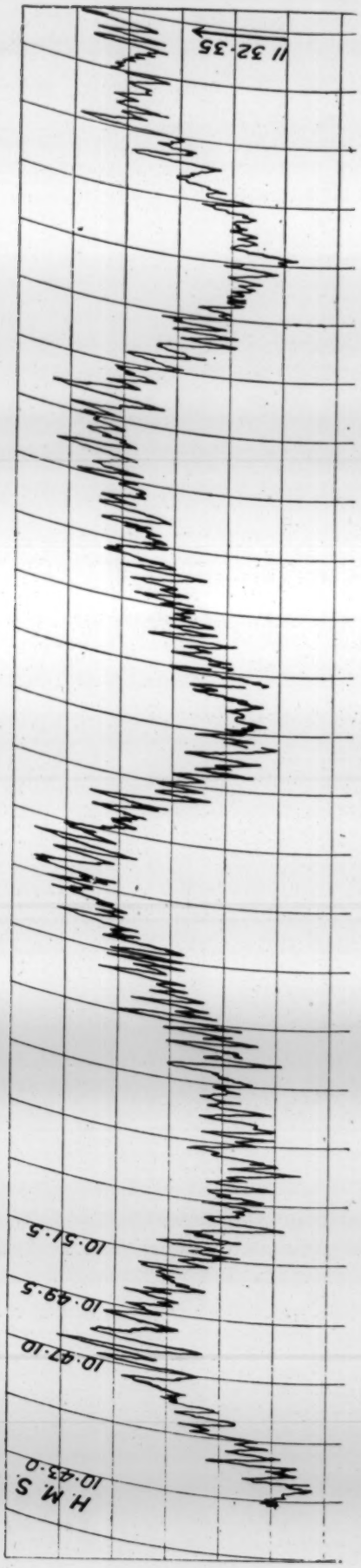

11 32·35
10·51·5
10·49·5
10·47·10
H M S
10·43·0

FIG. 11.

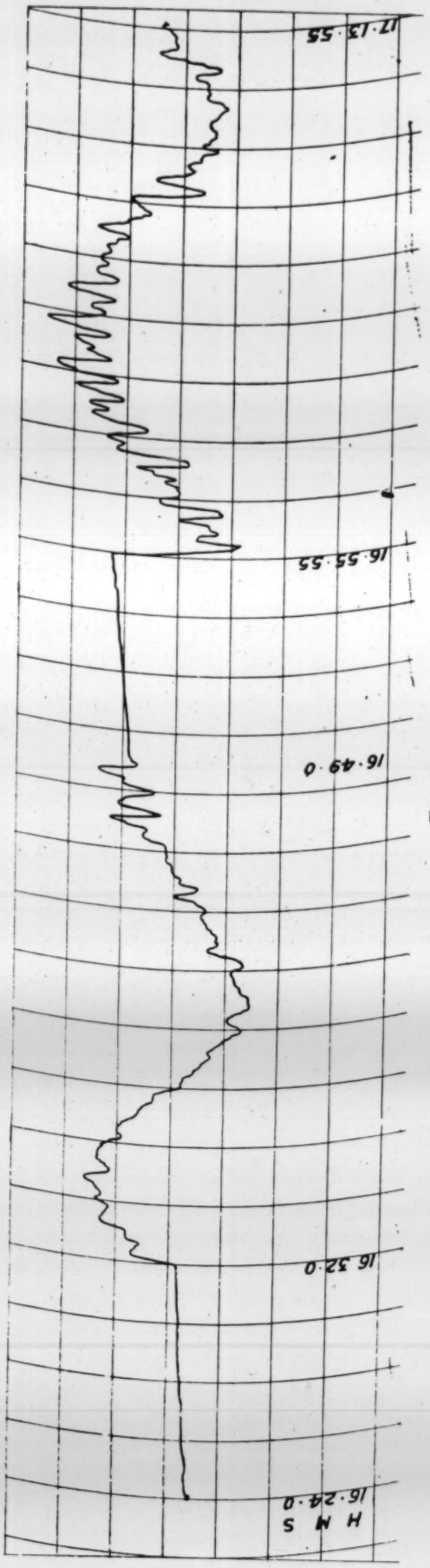

17·13·55
16·55·55
16·49·0
16·32·0
H M S
16·24·0

FIG. 12.

difference between the air-pressure at any moment and at the moment of closing. The curve in fig. 12 shows the result of making alternate limnographic and barographic observations, and led us to a very interesting conclusion, as will be explained in a later communication to the Society.

Use of the Statoscope as a Microbarograph.—If, instead of closing the stop-cock C, we allow it to open into an india-rubber tube fitted with a piece of thermometer tube of a proper length and bore, the statoscope becomes a microbarograph, and gives records

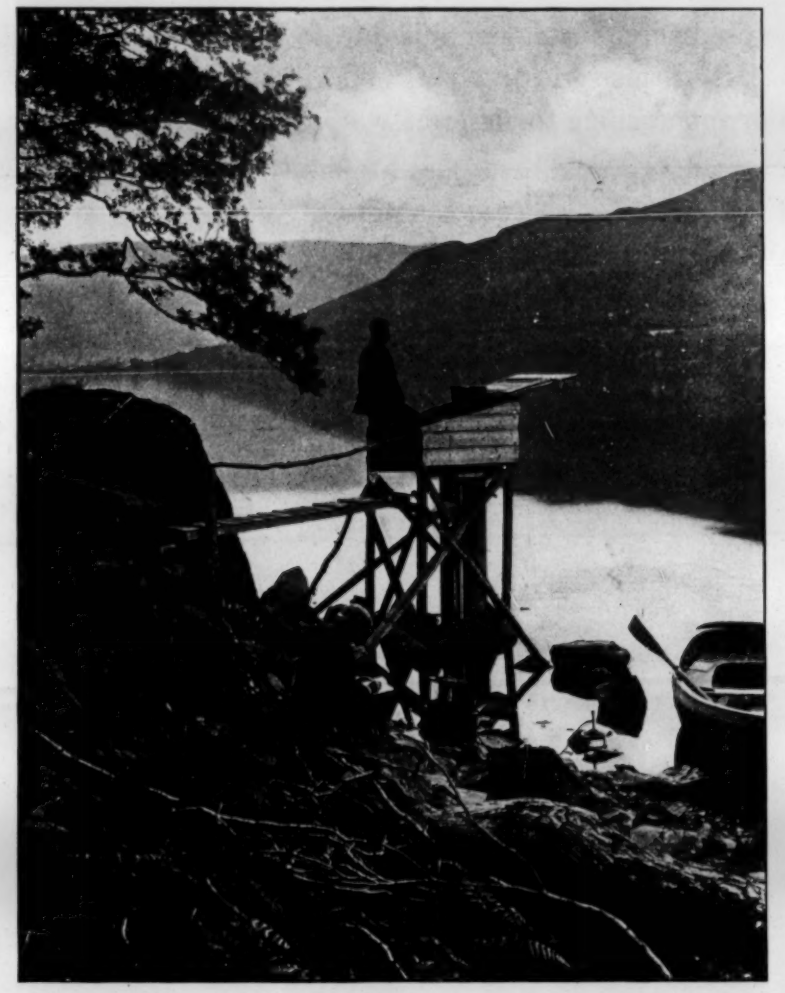


FIG. 13.

similar to the Dines-Shaw instrument, with the advantage of an opener time-scale and greater portability, but the disadvantage of running for a much shorter time.

USE OF HIGHLY PORTABLE LIMNOGRAPHS IN SEICHE SURVEYING.

There can be no doubt that the quickest method of making a survey of the seiches of a lake would be to use a couple of highly portable self-recording limnographs, each magnifying the range of the seiches by say, 4, and having a time-scale of, say, 5 mm. to a minute. By using one very portable self-recording instrument along with an

index limnograph, ENDRÖS * was able to carry out in little over a month a very complete survey of the Wagingersee, involving the determination of over a dozen different periods and at least seven nodal lines, an extraordinary result even for so skilled and practised an observer.

As the Sarasin instruments were useless for our purposes during the greater part of the available time in August and September, and it was desirable for general reasons to keep the new Waggon Recorder at St Fillans, we had to depend almost entirely on the use of index limnographs for the purposes of the general survey of Earn. The final form in which we used these instruments is due to Mr JAMES MURRAY, and is described in his paper (Part II. of this series).

I may take the opportunity to describe very briefly two particular forms of highly

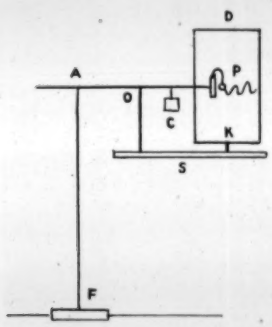


FIG. 14.

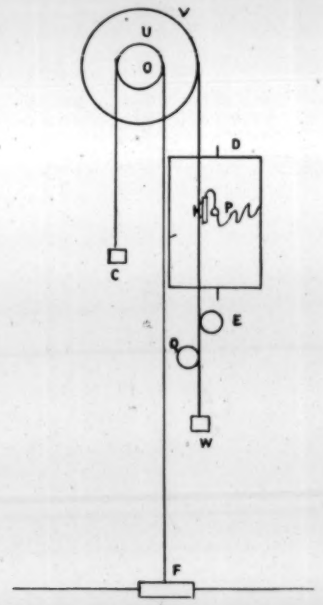


FIG. 15.

portable self-recording limnographs which, I think, might prove useful in seiche surveying.

The Lever Self-recording Limnograph is shown in a schematic diagram in fig. 14. As originally constructed, it was a toy made by one of my children for his own amusement out of such materials as he could beg from acquaintances; but an actual working instrument has been sent to Jerusalem to be used in preliminary observations on the Dead Sea.

A cord or wire from the float, F, can be attached at various parts of the lever, AOP, which is pivoted at O, and has a counterpoise C, whose weight or position can be varied. The recording drum, D, is driven by a cheap clock, which is screwed to the bottom of the drum, and whose arbor, K, is fixed to the stand S, which in its turn is mounted on a small hand-camera tripod stand. The pen, P, works on the swing-gate

* "Die Seiches des Waginger-Tachingersees," von ANTON ENDRÖS: *Sitz. ber. d. Kgl. Bayer. Akad. d. Wiss.*, Bd. xxxv., 1905, p. 447.

principle, and was copied from Dines' self-recording pressure tube anemograph, of whose excellent working we had good experience at St Fillans.

The instrument can obviously be arranged either to increase or to reduce the range of the seiche. That the pen draws ordinates which are circular arcs instead of straight lines is an objection, but by no means so serious in practice as might be supposed.

A selection of access tubes is supplied with the instrument, and also a well, into which the whole apparatus can be easily packed.

The Vertical Band Self-recording Limnograph.—If a rectilinear motion of the recording pen be insisted upon, probably an arrangement of the kind represented in the diagram of fig. 15 would be the best. U and V are two pulleys, of the same or of different diameters, on the same axis. A wire or cord from the float, F, drives U. Round V is wrapped the recording band, to which is fastened a swing-gate recording pen, P. The band is stretched by the counterpoise W, and steadied and guided by two small pulleys, E and Q, pushing it in opposite directions very slightly out of the vertical.

The whole apparatus could be mounted on the top of a suitable well, which would also serve as a case for carrying it.

The same principle could also be used for a fixed limnograph for recording seiches on a small time-scale. In that case the recording drum would be replaced by a suitable arrangement for drawing a vertical strip of paper past the recording pen.

Functions of the Well and Access Tube.

For a variety of reasons the float of a limnograph is usually placed in a cylindrical *Well*, to which the water of the lake is admitted by an *Access Tube*, which may be very short, even a mere hole in the wall of the cylinder, or may be of considerable length. The necessity for this arrangement, and its effect on the limnogram, will be best understood by considering the different natural causes that disturb the level at any given point of the lake surface. Omitting artificial disturbances, such as the passage of boats, etc., we have the following:—

(1) *Volume Denivellations*, caused by precipitation or by evaporation. The variation due to these is slow; and, if it is periodic, the period is usually long.

(2) *Persistent Wind Denivellations*, due to the heaping up of the water at one end of a lake when the wind blows steadily towards that end, or upon a shallow shelving shore or in a shallow bay, when the wind blows the water steadily towards the shore. These disturbances vary slowly; their duration is determined by the prevalence of the wind; and they are usually neither periodic nor rapidly fluctuating.

(3) *Fluctuating Wind Denivellations*,* due to the propagation of wave trains on the surface of the lake by the passage of wind squalls, and associated with the rapid variations of wind pressure shown by the self-registering anemograph.

* These were established by observations with the statolimnograph, and will be discussed in a later paper of this series.

(4) *Swell Denivellations.*—After a persistent wind has blown for a time over a certain stretch ("fetch") of water, a kind of dynamical equilibrium between wind and water is established; and the surface becomes covered with more or less regular trains of progressive waves. Owing to reflection at banks, retardation at shores and shallows, and probably also to unsteadiness in the wind, there is an interference of superposed trains, which spoils the regularity of the wave pattern and prevents absolutely regular periodicity in the denivellation at any given point. The effect to the eye is, however, a fairly regular pattern of small progressive waves of apparently constant length, usually diversified by wave maxima at approximately regular intervals. On Loch Earn common values for the periods of the smaller waves, and of the wave maxima, were two seconds and thirty seconds respectively. This wave system persists for some time after the wind falls; and it is at this stage that the name *swell* (*houle*, *vagues mortes*, *Dünung*, *Todte See*) is usually applied to it.

(5) *Seiche Denivellations*, which are stationary (standing) oscillations of the whole lake, having definite nodes and periods depending on the configuration of the basin.

If the object be to observe the seiche denivellation as little confused as possible by other disturbances of the lake level, the best place for a limnograph is on a rock or pier jutting into deep water and sheltered as much as possible from strong prevailing winds. We thus escape that part of the persistent wind denivellation which is due to shallowness near the shore, and in a great measure also the fluctuating wind denivellation and the swell. The effects of the two last can be further diminished by making the ratio of the diameter of the access tube to the diameter of the well sufficiently small; for, if this ratio be small, the tube takes a long time to fill the cylinder, and a maximum of level has been followed by a minimum before the rise has produced its full effect. Thus the narrowing or lengthening of the access tube diminishes the amplitude in the limnogram of disturbances of short duration or of short period, and at the same time causes the maxima or minima registered by the limnograph to lag in time behind the maxima or minima of the actual denivellations of the lake.

It must be observed that the same applies to seiches of short period. It follows, therefore, that by narrowing or lengthening the access tube, or both, we smooth the limnogram, not only by cutting out wind and swell disturbances, but also by reducing the amplitude of seiches of higher nodality.

In practice it is very often impossible to find a deep-water site for a limnograph anywhere near the part of the lake, *e.g.* near a node, where we wish to observe. In this case the difficulty is got over by placing the well in any convenient place and running an access tube out to water of sufficient depth, usually 8 to 10 feet.

It is easy to calculate the damping and retarding effect of the tube and well. In what follows we shall, for convenience, use C.G.S. units.

Let a and b be the diameters of the cylindrical well and access tube respectively; l the length of the tube; x and y the distances of the surface level in the well and in the lake respectively above any fixed point, say the outer end of the access tube.

It follows from the classical researches of OSBORNE REYNOLDS, "On the Motion of Water and on the Law of Resistance in Parallel Channels," * that, if the velocity in the access tube does not exceed $w_c = 2008\nu/b$, where ν is the viscosity of water at the temperature θ°C, viz., $\nu = \cdot0178/(1 + \cdot0337\theta + \cdot000221\theta^2)$, then the resistance in the tube will be proportional to the mean velocity of flow, and we can apply the well-known formula of POSEUILLE to calculate the difference of pressure at the two ends of the tube for a given velocity of flow.

For a seiche of recorded amplitude B, and period T, the maximum velocity of rise or fall of level is $2\pi B/T$, which gives a velocity of $w_b = 2\pi B a^2/b^2 T$ in the access tube. Now, in Loch Earn the range recorded rarely exceeded 4 cm.; so that $B = 2$. We may take $a = 15$ cm., which was about the diameter of the small wells used with the index limnographs. Taking the temperature of the water to be 17°C, so that $\nu = \cdot0109$, we get, for the uninodal seiche of Earn ($T = 870^{sec}$):—

$$w_c = 21\cdot89/b,\ w_b = 3\cdot250/b^2.$$

Hence the following table for the three diameters b which were actually used:—

b	w_c	w_b
1·27	17·23	2·02
·63	34·74	8·19
·47	46·36	14·71

The actual maximum is in all cases well under the critical velocity.†

Since the motion is very slow, we may treat it as steady, and then we have at any time t, by POSEUILLE's Law:—

$$-\pi\frac{a^2}{4}\frac{dx}{dt} = \frac{\pi b^4 g(x-y)}{128\nu l} \quad . \quad . \quad . \quad . \quad . \quad (1).$$

Hence, taking $\nu = \cdot0109$, $g = 982$, and putting

$$\chi = gb^4/32\nu l a^2 = 2813b^4/la^2 \quad . \quad . \quad . \quad . \quad . \quad (2),$$

we get

$$\frac{dx}{dt} = -\chi(x-y) \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Let us now suppose that the lake level is subject to a harmonic denivellation of amplitude A and period T; then, if $n = 2\pi/T$, and d be the mean depth at the opening of the access tube, we shall have $y = A \sin nt + d$; and, therefore,

$$\frac{dx}{dt} + \chi x = \chi A \sin nt + \chi d \quad . \quad . \quad . \quad . \quad . \quad (4).$$

* *Phil. Trans. Roy. Soc. Lond.*, 1883.

† It should be noticed that this is not the critical velocity ($u_c = 13000\nu/d$) at which turbulent motion begins. The critical velocity v_c at which the resistance begins to be proportional to (velocity)^n, where n is a number varying from, say, 1·72 to 2·00, is again different, viz., $v_c = 1\cdot325 w_c$.

From (4) we get

$$x = d + Le^{-\chi t} - \chi A(n \cos nt - \chi \sin nt)/(n^2+\chi^2),$$

where L is an arbitrary constant; or, if we determine τ by the equation

$$\tan n\tau = n/\chi \quad . \quad . \quad . \quad . \quad . \quad (5),$$

$$x = d + Le^{-\chi t} + A \cos n\tau \sin n(t-\tau) \quad . \quad . \quad . \quad . \quad (6).$$

If a considerable time has elapsed from the beginning of the observation, so that the water-level in the well has lost its initial disturbance, the term $Le^{-\chi t}$ may be neglected; and we have :—

$$x - d = A \cos n\tau \sin n(t-\tau) \quad . \quad . \quad . \quad . \quad (7).$$

That is to say, the harmonic oscillation of the lake level as registered by the limnograph is retarded by the time interval ("lag"),

$$\tau = (1/n) \tan^{-1}(n/\chi) \quad . \quad . \quad . \quad . \quad . \quad (8),$$

and "damped" in the ratio

$$\cos n\tau : 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

If we put $z = n/\chi$, then $\tau = (1/\chi) \tan^{-1}z/z$. Hence, since $\tan^{-1}z/z$ diminishes continuously from 1 to 0 as z varies from 0 to $+\infty$, it follows that the lag diminishes as the nodality of the seiche increases, and increases as χ diminishes.

It is obvious from (5) and (8) that the amount of damping increases (that is, the ratio of damping decreases) as the nodality increases, or as χ decreases.

On the other hand, since

$$\tau/T = (1/2\pi) \tan^{-1}(n/\chi) \quad . \quad . \quad . \quad . \quad (10),$$

the fraction τ/T, which we may call the "relative lag," increases with increase of nodality or with decrease of χ, its maximum possible value being $\frac{1}{4}$. So that the greatest possible lag for any seiche is a quarter of its period.

The following numerical tables will help to give a clear picture of the effect of the relative sizes of well and access tube on seiches of different periods, chiefly such as occur or might occur on Loch Earn :—

(A) *Forel's Limnograph at Morges.*

$l = 840$ cm., $a = 160$ cm., $b = 6$ cm.

$\chi = \cdot1697$, $\log \chi = \bar{1}\cdot22961$, $\log (2\pi/\chi) = 1\cdot56857$.

T	τ/T	τ	$\cos n\tau$
sec		sec	
4380	·00135	5·88	·9999
2100	·00281	5·88	·9998
600	·00979	5·87	·9981
300	·0195	5·85	·9925
60	·0879	5·27	·8511

(B) *New Limnograph at Pic-Nic Point.*

$l = 965$ cm., $a = 35$ cm., $b = 2{\cdot}5$ cm.

$\chi = {\cdot}09303$, $\log \chi = \bar{2}{\cdot}96862$, $\log (2\pi/\chi) = 1{\cdot}82956$.

T	τ/T	τ	cos $n\tau$
sec		sec	
870	·0123	10·7	·9970
486	·0220	10·7	·9904
342	·0310	10·6	·9811
60	·1344	8·1	·7476

(C) *Sarasin Limnograph at the Binode.*

$l = 60$ feet $= 1830$ cm., $a = 35$ cm., $b = 1\frac{1}{2}$ inch $= 3{\cdot}75$ cm.

$\chi = {\cdot}2483$, $\log \chi = \bar{1}{\cdot}39506$, $\log (2\pi/\chi) = 1{\cdot}40312$.

T	τ/T	τ	cos $n\tau$
sec		sec	
870	·00463	4·02	·9996
486	·00828	4·02	·9986
342	·01175	4·02	·9973
60	·06351	3·81	·9215

(D) *Index Limnograph* with 6-inch well, and 6 feet tube of $\frac{1}{2}$-inch, $\frac{1}{4}$-inch, or $\frac{3}{16}$-inch bore.

$l = 182$ cm., $a = 15$ cm.

	$b = 1{\cdot}27$ cm. $\chi = {\cdot}1788$			$b = {\cdot}63$ cm. $\chi = {\cdot}01083$			$b = {\cdot}47$ cm. $\chi = {\cdot}003355$		
T	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$
sec		sec			sec			sec	
870	·0064	5·59	·9992	·0937	81·5	·8320	·1808	157·3	·4213
486	·0115	5·58	·9974	·1390	67·6	·6421	·2096	101·8	·2512
342	·0163	5·57	·9948	·1569	53·7	·5078	·2213	72·5	·1797
60	·0843	5·06	·8630	·2336	14·0	·1028	·2449	14·7	·0320

(E) *Index Limnograph* with 6-in. well, and 12 ft. tube of $\frac{1}{2}$-in., $\frac{1}{4}$-in., or $\frac{3}{16}$-in. bore.

$l = 364$ cm., $a = 15$ cm.

	$b = 1{\cdot}27$ cm. $\chi = {\cdot}08942$			$b = {\cdot}63$ cm. $\chi = {\cdot}005415$			$b = {\cdot}47$ cm. $\chi = {\cdot}001678$		
T	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$
sec		sec			sec			sec	
870	·0128	11·1	·9968	·1476	128·4	·5997	·2137	185·9	·2264
486	·0229	11·1	·9897	·1864	90·6	·3864	·2294	101·8	·1288
342	·0323	11·0	·9795	·2044	69·9	·2826	·2355	80·5	·0909
60	·1375	8·3	·6494	·2412	14·5	·0518	·2475	14·9	·0160

(A), (B), and (C) illustrate cases where the dimensions of the apparatus are so chosen that there is practically no damping even of seiches whose period is only a minute. It will be observed that the lag is in each case the same for each of the four seiches, and is scarcely noticeable in practice.

In table (D) is shown the effect of varying the diameter of the access tube, keeping its length and the diameter of the well fixed. With the $\frac{1}{2}$-inch tube, the lag is practically the same for all the four seiches; and it is only for the 60^{sec} seiche that the damping is perceptible, viz., about 14 per cent. With the $\frac{1}{4}$-inch tube, the absolute lag is no longer negligible even for the 60^{sec} seiche; and it varies greatly, being nearly six times as much for the 870^{sec} seiche as for the 60^{sec} seiche. The damping for the seiche of longest period is now greater than it was in last case for the seiche of shortest period; and the 60^{sec} seiche is reduced by 90 per cent. It is obvious, therefore, that the use of the $\frac{1}{4}$-inch tube must have produced very marked distortion in any limnogram in which all the four seiches have any sensible amplitude.

With the tube of $\frac{3}{16}$-inch bore, while the lag for the 60^{sec} seiche is little greater than before, the lag of the 870^{sec} seiche is now over $2\frac{1}{2}^{min}$; the amplitude of the 870^{sec} seiche is reduced by 58 per cent., and the amplitude of the 60^{sec} seiche by 97 per cent.

Comparison between tables (D) and (E) shows the effect of lengthening the access tube, other things being equal.

It is now clear that by lengthening or contracting the access tube, or by increasing the diameter of the well, we have a means of simplifying the limnogram by eliminating from it partially, or in some cases practically wholly, seiches of higher nodality. And we also see that when this is done we introduce both lag and damping, which may have to be allowed for, especially when we are comparing the indications of different limnographs with a view to the determination of phase differences and the location of nodes.

To give an idea of the observed facts, I reproduce two sets of paired observations with index limnographs taken by Messrs MURRAY and FRASER at the E. binode of Earn on

7th July and 8th August 1905. Six-inch wells were used in every case. In the original limnograms the seiche was multiplied by four, and the time-scale was ·2 inch per minute. In the reproduction the scale is $\frac{3}{4}$.

In Fig. 16, the upper limnogram A B was taken with 6 feet of $\frac{1}{2}$-inch tube; the part C D of the lower with two access tubes each $\frac{1}{4}$-inch diameter; the part D E with 6 feet of $\frac{1}{2}$-inch tube. It will be seen that the part C D is much smoother than the simultaneous limnogram above it, and that there is well-marked damping and considerable lag. On the other hand, the part D E goes *pari passu* with the simultaneous portion of A B above it. Anything like exact conformity could not be expected, as the curves are plotted from half-minute eye observations. Owing to accidental wind disturbances, accurate quantitative determinations of damping and lag from such an observation are impossible.

In fig. 17 is given the result of a similar pair of simultaneous observations. A B was taken with 6 feet of $\frac{1}{4}$-inch tube; C D with 12 feet of $\frac{1}{4}$-inch tube; and E F with 12 feet of $\frac{1}{2}$-inch tube.

Experimental Determination of the Reduction Constant χ.

The constant χ, which plays so important a part in the theory of the ordinary limnograph, could scarcely be calculated with much accuracy from the dimensions of the apparatus. The best method would be to determine the lag and damping of oscillations of known period and range artificially produced, which could be done in a laboratory without much difficulty.

A rough determination of χ at the lake side could be made on a day when there is no seiche,* by observing the times that the level in the well takes to fall through given distances after it has been disturbed by pouring water into the well.

Suppose that at time $t = 0$, the level of the well is h cm. above the normal height; then, there being no seiches, $A = 0$; and we have from (6) $x = d + Le^{-\chi t}$. When $t = 0$, $x = d + h$; hence $L = h$. Therefore $x - d = he^{-\chi t}$. Let the level at times t' be h'; then we have $h' = he^{-\chi t'}$. Whence $\chi = \log_e(h/h')/t'$.

Theory of the Statolimnograph.

For simplicity, we suppose the instrument so adjusted that the mean level of the water in the well is the same as the mean level of the lake, and that the pressure inside the cylinder of the statoscope is equal to the atmospheric pressure when the water in the well is at mean level. And we also suppose that neither the temperature of the air inside the statoscope nor the atmospheric pressure outside varies.

* Or even when there is a small regular seiche giving a smooth limnogram.

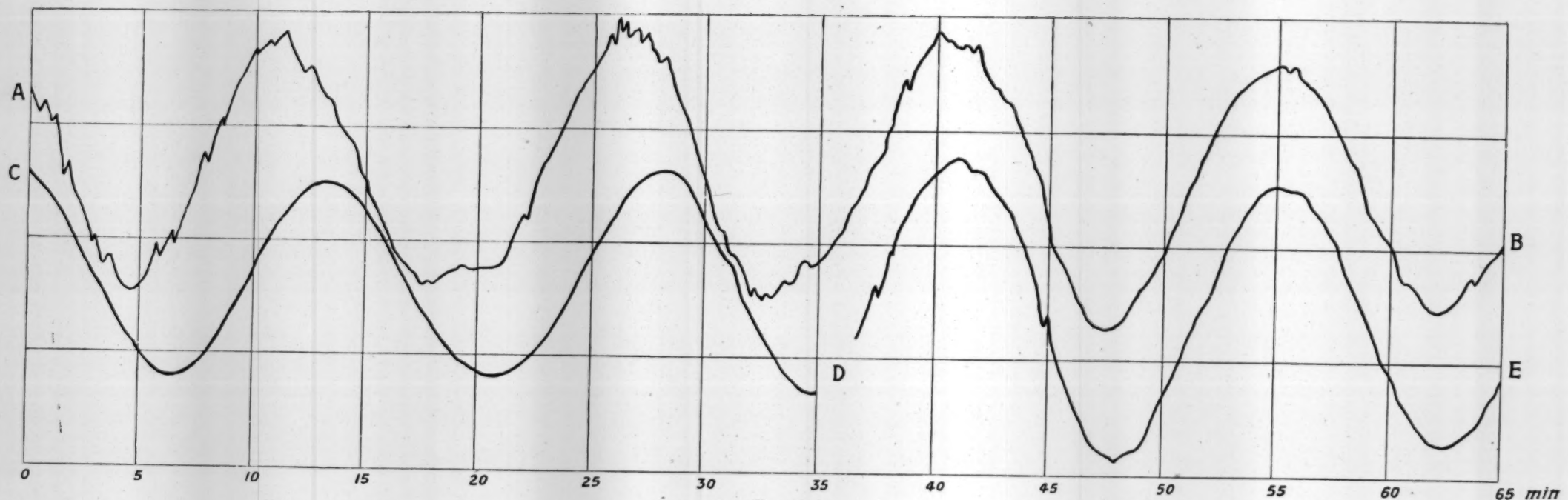

A
C
D
B
E
0
5
10
15
20
25
30
35
40
45
50
55
60
65 min

FIG. 16.

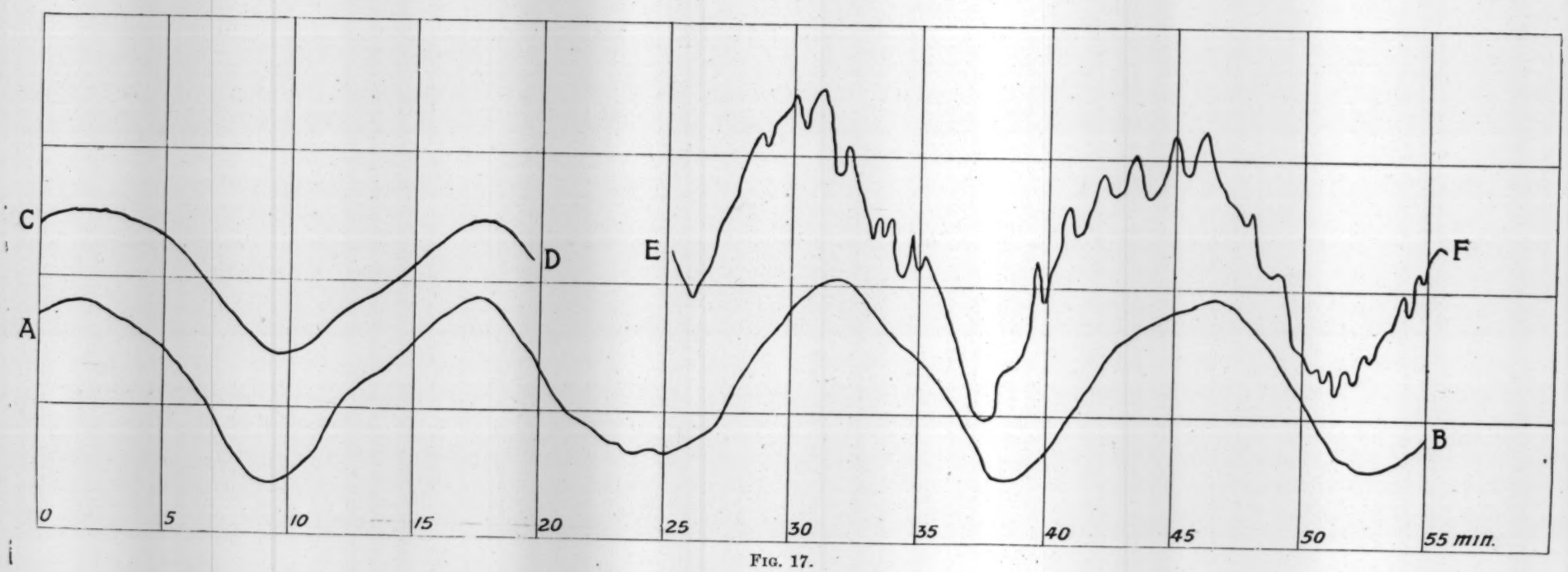

C
D
E
F
A
B
0
5
10
15
20
25
30
35
40
45
50
55 min.

FIG. 17.

Taking C.G.S. units, as before, let v be the volume of the statoscope cylinder together with the connecting tube and the part of the well occupied by air;

w be the section, and a the diameter of the well, so that $w = \pi a^2/4$;

l the length and b the diameter of the access tube;

x and y the heights above mean level at time t of the water-level in the well and outside in the lake respectively;

p the pressure of the air inside the well and statoscope; ω the atmospheric pressure. Then

$$p - \omega = \omega wx/(v - wx) = \omega wx/v \quad . \quad . \quad . \quad . \quad (11),$$

since x is small.

The equation (3) of p. 375 is therefore replaced by

$$\frac{-\pi a^2}{4}\frac{dx}{dt} = \left\{\frac{\omega wx}{v} + g(x-y)\right\}\frac{\pi b^4}{128\mu l}.$$

Hence we have

$$\frac{dx}{dt} + (\phi + \chi)x = \chi y \quad . \quad . \quad . \quad . \quad (12),$$

where

$$\left.\begin{aligned}\phi &= \pi\omega b^4/128\mu lv,\\ \chi &= gb^4/32\mu la^2\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (13);$$

so that

$$\frac{\phi}{\chi} = \frac{\pi\omega a^2}{4gv} \text{ and } \frac{\omega w}{v} = \frac{g\phi}{\chi} \quad . \quad . \quad . \quad . \quad (14).$$

If now we consider a seiche of period $2\pi/n$, so that $y = \mathrm{A}\sin nt$, we get

$$x = \left(\frac{\chi}{\phi + \chi}\right)\mathrm{A}\cos n\tau \sin n(t-\tau) \quad . \quad . \quad . \quad (15),$$

where

$$\tan n\tau = n/(\phi + \chi) \quad . \quad . \quad . \quad . \quad . \quad (16).$$

The reading of the instrument is proportional to the difference between the pressure in the cylinder and in the outside air, *i.e.* to $p - \omega$, which is equal to $(\omega w/v)x$. Using (14), we get

$$p - \omega = \{g\phi/(\phi + \chi)\}\,\mathrm{A}\cos n\tau \sin n(t-\tau) \quad . \quad . \quad . \quad (17).$$

Essentially, therefore, a statolimnograph acts like an ordinary limnograph whose reduction constant has been increased by ϕ.

For the well actually used $a = 14{\cdot}3$ cm.; and v, which varied a little according as the well was placed more or less deeply in the lake, would be about 1600π cm. From these data we find ϕ/χ to be about 33. Speaking roughly, therefore, the statolimnograph acts like an ordinary limnograph whose reduction constant is $\phi = \pi\omega b^4/128\mu lv$; or, more exactly, in our particular arrangement, like an ordinary limnograph having a reduction constant thirty-four times as large as that belonging to the well and access tube actually used.

The magnification for infinitely slow alterations of pressure was found by actual experiment to be about $3{\cdot}72$.

In fig. 18 are given tracings of an actual seiche record taken on Loch Earn on the 14th September 1905. In taking the curve 2, an access tube 12 feet long of $\frac{3}{16}$-inch diameter was used; in taking the curves 1 and 3, 6 feet of $\frac{1}{4}$-inch diameter. In the interval between 12^h55^m and 14^h25^m the state of the lake had altered very little. The lower trace is interesting, as it gives an automatic record of the finer denivellations—or vibrations, as FOREL calls them—which could not be accurately registered by the most skilful eye observations, and which would be almost invisible on one of the large self-registering limnographs running at the ordinary speed of 1 mm. per minute. These vibrations are also beautifully shown in figs. 10 and 11.

If the instrument were to be constructed specially with a view to seiche observations, the above theory suggests several obvious modifications which it is needless to discuss here.

ON THE REDUCTION OF LIMNOGRAPHIC MEASUREMENTS, THE METHOD OF RESIDUATION, ETC.

The deduction of the periods, not to speak of the nodes, of the various seiches of a lake from limnograms taken at various points, and under various conditions, is by no means so simple a problem as appears at first sight.

It has been proposed to apply the harmonic analyser to the discussion of limnograms; but this is not possible, at least directly, for the harmonic analyser simply enables us to deduce the amplitudes of harmonic components whose periods are known or assumed *a priori*. But the periods are precisely what we have in the first instance to determine from the limnogram itself.

If only one seiche appeared at a time, unaccompanied by any other denivellation, it would simply be necessary to measure the time between two distant maxima or minima and divide by the number of oscillations between. It is, however, very rare that a pure seiche prevails for more than a very short time. During August and September 1905, the new limnograph at St Fillans on Loch Earn may be said to have never drawn a straight line; yet in all that time it gave scarcely a single certain example of a pure seiche.

Use of the Configuration Period.—The most commonly occurring type of seiche on Loch Earn is a more or less pure dicrote, in which the uninodal and binodal are the predominant components. Figs. 3 and 4 are reproductions of good examples. Such seiches are occasionally very persistent on Earn. When the new limnograph was at Lochearnhead, a dicrote seiche was traced continuously, although with varying amplitudes and varying embroidery, from about 8^h30^m on 16th October to 20^h15^m on 22nd October 1905.

Owing to the accurate or approximate commensurability of the periods T_1 and T_2 of the uninodal and binodal, the limnogram of a protracted seiche of the kind just alluded to consists of a repetition of a certain portion, which we may call the "Con-

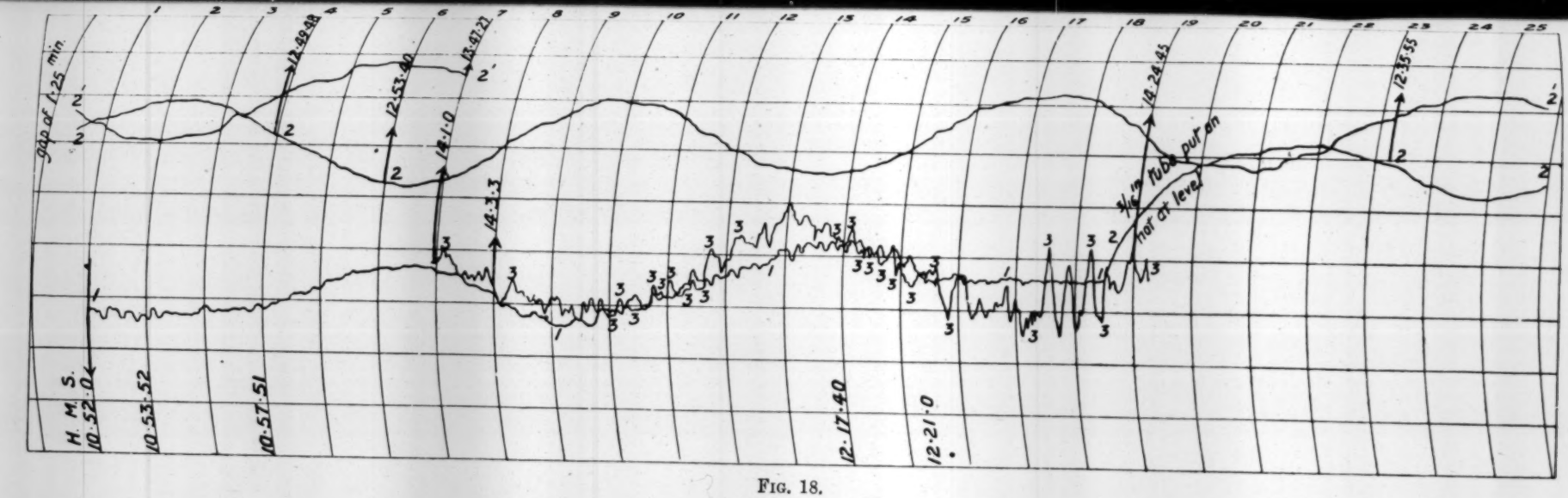

Gap of 1·25 min.
12·49·48
12·53·40
12·57·22
13·1·0
14·3·3
14·24·45
12·35·55
¼" tube put on
H. M. S.
10·52·0
10·53·52
10·57·51
12·17·40
12·21·0

FIG. 18.

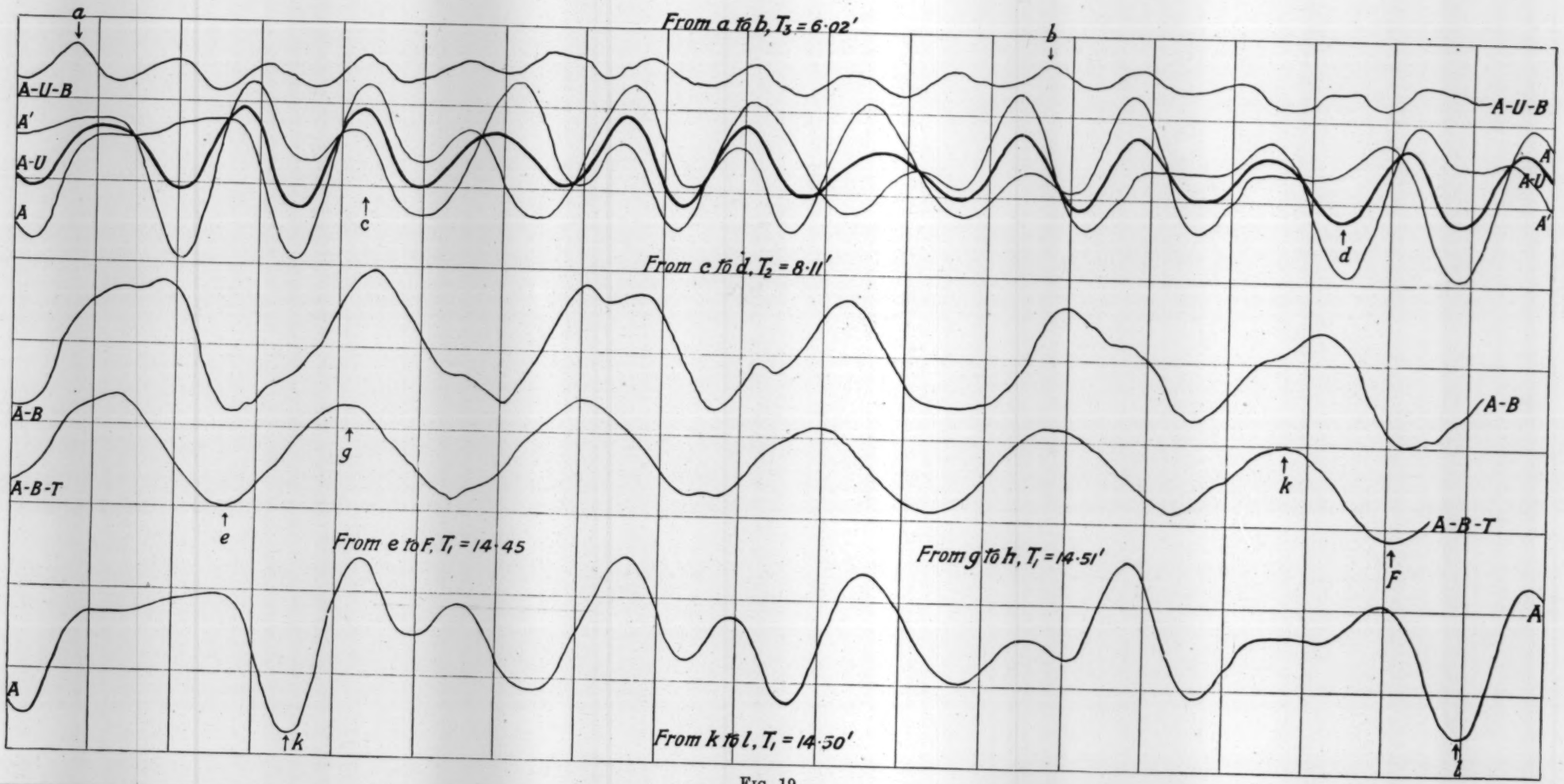

From a to b, T3 = 6·02′
From c to d, T2 = 8·11′
From e to F, T1 = 14·45
From g to h, T1 = 14·51′
From k to l, T1 = 14·50′
A-U-B
A′
A-U
A
A-B
A-B-T
a
b
c
d
e
F
g
k
l

FIG. 19.

figuration Period" of the limnogram. Thus, for example, taking the calculated values of T_1 and T_2 for Loch Earn, we have $T_2/T_1 = 14{\cdot}50/8{\cdot}14 = 1{\cdot}781$. If we convert T_2/T_1 into a continued fraction, we get

$$\frac{T_2}{T_1} = 1 + \frac{1}{1+}\ \frac{1}{3+}\ \frac{1}{1+}\ \frac{1}{1+}\ \frac{1}{2+}\ \frac{1}{1+}\ \frac{1}{12},$$

the third convergent to which is $9/5 = 1{\cdot}8$; and this represents the value of T_2/T_1 with an absolute error of less than ·02. Hence five uninodal oscillations of the lake occupy very nearly the same time as nine binodal oscillations. Therefore a portion of the limnogram consisting of five uninodal, or nine binodal, oscillations, will be observed to recur a considerable number of times; and would recur for ever if 9/5 were the exact value of T_2/T_1, and the dicrote seiche persisted indefinitely without decay or disturbance.

Fig. 4 shows three such configurations in a dicrote seiche of Loch Earn, registered at St Fillans on 6th September 1905.

The existence of a well-marked configuration period gives us two great advantages. By looking for points of symmetry we can determine very accurately when the two seiches are both at a maximum, both at a minimum, or one at a maximum and the other at a minimum; also, when the time-length of the configuration period is known, and also the period of one of the seiches of the dicrote, the other period can be calculated.

By observing near a Binode or near the Uninode we eliminate the binodal and uninodal seiches respectively. As the trinodal and higher seiches on Earn are infrequent, and nearly always of small range, we thus obtain curves which, apart from non-seiche disturbances, are very nearly sinusoidal. Fig. 7 is an example. We secured a considerable number of such series; and, but for the defective working of our Sarasin limnographs, would have got many more. These give good determinations of T_1 and T_2, on the assumption that the seiche has undergone no change of phase during the series. Undoubtedly such changes do occur; they are probably due to the intermittent action of the cause which produces the seiche. In this way two seiches of the same period are superposed, the apparent result being a change in phase, with or without a change in amplitude. A sudden and considerable change of phase would, of course, be noticeable; but small or gradual changes of phase would certainly escape notice.

The observation on a large scale of short series of comparatively pure sinusoidal undulations also give good period-determinations. For this purpose index limnographs magnifying the range of the seiche fourfold, and limnograms having a time-scale of ·2 inch (5 mm.) per minute, were used; and occasionally the statolimnograph. By bisecting lines drawn across the undulation parallel to the time-scale we can judge very accurately of the symmetry of the particular part of the limnogram, and infer whether the turning-point was or was not much disturbed by higher seiches or other disturbances. When two turning-points are determined in this way, we get of course a determination of the period, and the advantage of the method is that the result is not so likely to be vitiated by change of phase.

A combination of the two last methods can sometimes be employed with advantage when the fixed limnograph is registering a long sinusoidal series. The index limnograph can be used to give very accurately the times of two turning-points, and the fixed limnograph used simply to count the intervening oscillations; but this does not eliminate error due to disturbance of phase.

Method of Residuation.—In practice on Loch Earn, more particularly in our attempts to determine the positions of the nodes, we were compelled to work with short, large-scale limnograms; and the seiches were rarely pure. In these cases we resorted very often to a certain way of treating the limnogram, which we came ultimately to call "Residuation."

Consider a compound seiche, the equation to whose limnogram is

$$y = A_1 \sin \frac{2\pi}{T_1}(t - \alpha_1) + A_2 \sin \frac{2\pi}{T_2}(t - \alpha_2) + \quad . \quad . \quad . \quad (18).$$

Construct a new curve by slipping the curve (18) a distance τ backwards along the t-axis, and from these two curves form a new one by adding the ordinates; or, what comes to the same thing, derive from (18) a new curve by adding to the ordinate at each point the ordinate of the point whose abscissa is greater by τ.

The equation of the resulting curve is

$$\eta = 2A_1 \cos \frac{\pi\tau}{T_1} \sin \frac{2\pi}{T_1}\left(t - \alpha_1 + \frac{\tau}{2}\right) + 2A_2 \cos \frac{\pi\tau}{T_2} \sin \frac{2\pi}{T_2}\left(t - \alpha_2 + \frac{\tau}{2}\right) + \quad . \quad . \quad (19).$$

The derived curve, or *residual with respect to* τ, contains in general all the harmonic oscillations of the original. The phase of each compound is retarded by the same time, $\frac{1}{2}\tau$; and the amplitudes are altered in different proportions, viz., $2 \cos (\pi\tau/T_1) : 1$, $2 \cos (\pi\tau/T_2) : 1$, etc.

Suppose, in particular, that we put $\tau = \frac{1}{2}T_1$; then the first component disappears altogether, and we get a curve, whose equation is

$$\eta_1 = 2A_2 \cos \frac{\pi T_1}{2T_2}\left(t - \alpha_1 + \frac{T_1}{2}\right) + \text{etc.} \quad . \quad . \quad . \quad (20).$$

This last curve we call *the residual of the limnogram with respect to the seiche of period* T_1.

To show how this may be used in practice, suppose we have a short, large-scale limnogram, the principal or only components in which are the uninodal seiche (T_1) and the binodal (T_2). In general, one, say the uninodal, will predominate; the other may be scarcely perceptible at first sight. Selecting two turning-points,* we divide the difference between the corresponding points by the number of intervening major oscillations. The result will be an approximation to T_1, say T'_1; but generally only an approximation, because the turning-points are displaced by the other seiches, mainly by the binodal.

* Points of symmetry, of course, if such are available.

Now residuate with respect to T'_1. The result will be a curve in which the uninodal harmonic is very much reduced, and will show the binodal in predominance. From this determine an approximation to T_2, say T'_2.

Now return to the original limnogram, and residuate with respect to T'_2. The result will be a curve from which the binodal harmonic is nearly absent. Hence the turning-points of the uninodal will be much less disturbed than before; and we can now get a better approximation to T_1, say T''_1.

Residuate now the original limnogram with respect to T''_1, and we get a curve in which the binodal is less disturbed than before. We can therefore make a closer approximation, say T''_2, to T_2; and so on.

The process can, if necessary, be repeated until the accumulated errors incidental to the manipulation obliterate the essential features of the diagram with which we are dealing.

In this way the periods of two or even three seiches can be determined, one after the other, from a comparatively short large-scale limnogram. We discovered in this way seiches the existence of which had not been suspected; and without this process we should not have obtained a determination of the period of the trinodal seiche of Earn at all, which never occurred pure, and had always a comparatively small range. The process was also used in purifying compound limnograms with a view to determine nodes.

Fig. 19 (scale $\frac{1}{2}$) reproduces an actual application of the method of residuation. At St Fillans, on the 10th July 1905, Mr JAMES MURRAY made with an index limnograph* one of the most remarkable seiche observations with which I am acquainted. He observed every half-minute from 9.30 A.M. to 5.35 P.M. During the whole time the lake was calm and the seiche steady. The limnogram presented very clearly to the eye the configuration of a dicrote composed of the uninodal and binodal seiches of Earn, and this was repeated four times during the observation. The lowest curve, A A in fig. 19, is rather less than the third part of the limnogram as plotted by Mr MURRAY. Measuring from k to l, which are two nearly symmetric mimima on A A, we get $T'_1 = 14{\cdot}5'$. In second part of fig. 19, A A is as before, and A′A′ is the same curve slid backwards a distance corresponding to $7{\cdot}25'$. The third (thick black) curve, A – U, bisects everywhere the vertical distance between A A and A′A′, and is therefore the residual curve as above defined with the scale of ordinates halved. It is at once obvious that it is mainly a dicrote of the binodal and another seiche, the time-length of the configuration period being three periods of the binodal. Measuring from c to d, we get $T'_2 = 8{\cdot}02$.

After residuating in the ordinary way with respect to T'_2, we get the curve A – U – B, on measuring which from a to b we get $T'_3 = 6{\cdot}02'$. We thus get, obviously, a close approximation to the period of the trinodal seiche, the existence of which was not suspected in the original limnogram.

* It was mounted on friction wheels, and magnified the seiche about four and a half times. Time-scale of limnogram, ·2 inch per minute.

The curves A – B and A – B – T show the result of residuating out successively the binodal and trinodal seiches, by means of the approximate periods $T'_2 = 8{\cdot}02$, $T'_3 = 6{\cdot}02$. The curve A – B – T thus purified still shows departure from pure sinusoidality, some, but probably not all, of the disturbance being accidental, due, say, to slight puffs of wind. As it stands, it gives $T''_1 = 14{\cdot}45$ from e to f; and $T''_1 = 14{\cdot}51$ from g to h. Assuming the watch error to be negligible, we have thus set comparatively close limits to the uninodal period of Loch Earn; and we now see that $T_2 = 8{\cdot}08'$ and $T_3 = 6{\cdot}02'$ must be very close to the true values of the Binodal and Trinodal periods corresponding to the depth of the lake on 10th July 1904.

PART II.

In the early summer of 1905 the observation of the seiches of Loch Earn was undertaken, under the direction of Professor CHRYSTAL. The apparatus employed consisted at first of two Sarasin limnographs, and two small portable limnographs on the model of ENDRÖS.

The permanent recording limnographs were intended to be set up at the Uninode and Binode, the positions of which had been calculated by Professor CHRYSTAL. The positions of the nodes were to be checked experimentally by the index limnometers; but the weather conditions at the time were unfavourable, and we adhered to stations near the calculated positions, which proved to be accurate enough for the object in view, viz., the elimination of one of the principal seiches at each node.

THE SARASIN LIMNOGRAPHS.

Situation.—At both of the nodes selected as the stations for the permanent limnographs, viz., the Uninode and the East Binode, the shore of the loch presented a very gently sloping beach, some 60 feet broad, terminating landward against rock a few feet from the edge of the water. In the lake, beyond the storm beach, the slope was very rapid into deep water. These conditions rendered impracticable two of the approved methods of setting up limnographs. The first method, afterwards adopted with Professor CHRYSTAL'S limnograph near St Fillans, is to place the cylinder directly in fairly deep water; the second method (recommended by ENDRÖS) is to dig a well inland, at some distance from the loch, and to connect it with the loch by a tube.

Here a compromise had to be made, and a well about 2 feet deep was dug in the loch itself.

The Staging.—To support the instrument a wooden framework was built, the essential structure of which, and the disposition of the various parts of the instrument, can be seen from the accompanying figure.

A horizontal triangular frame was first laid down over the well as a foundation. The apex of the triangle projected a few feet into the loch, and the shoreward base was weighted with heavy stones. Three vertical posts were then fixed to this foundation, to carry the platform. The upright at the apex of the triangle is the most important, as it goes into the loch and steadies the whole erection. It is therefore pointed, and driven a short distance into the gravel, being prevented by a cross-piece from sinking deeper during the movements of the gravel in stormy weather. The

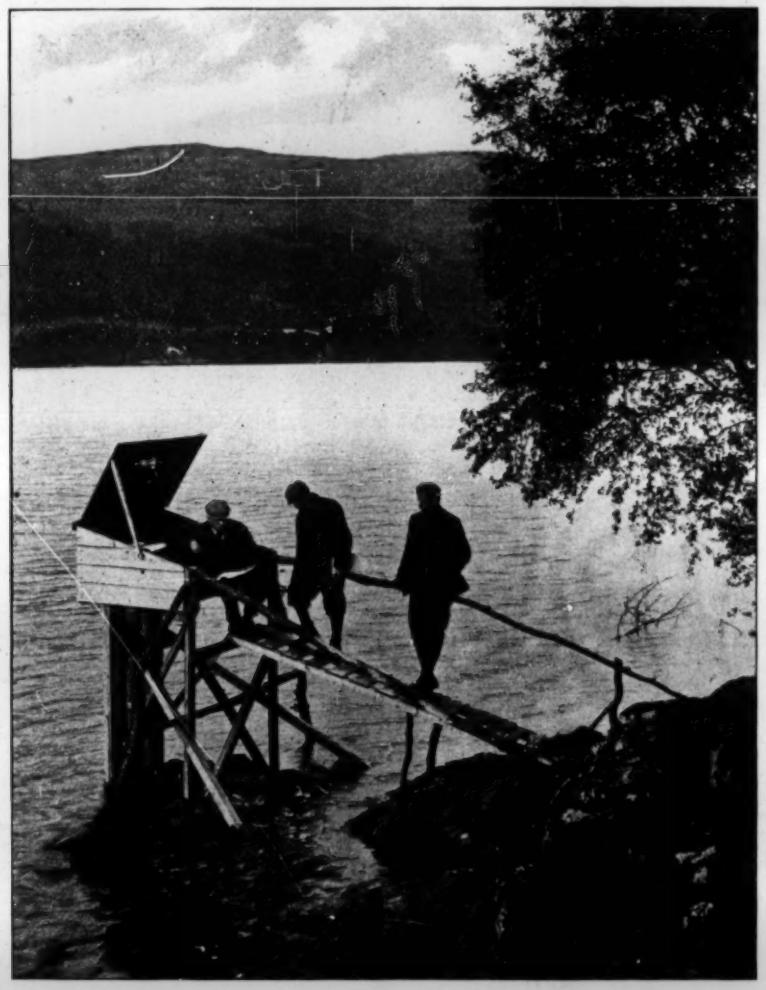


FIG. 20.—The Sarasin Limnograph at East Binode, near Ardtrostan House, showing staging and shelter-hut over limnograph.

triangular platform was built about 6 feet above the normal low level of the loch, to allow for the rise that occurs in ordinary spates.

The whole frame was securely stayed in all directions. The cylinder fitted into the apices of the two horizontal triangles, and was kept in place by cross-pieces: it was found necessary to have several of these in the length of the cylinder, to prevent its destruction during storms. The box containing the recording part of the apparatus was placed on the platform, and a rough little hut built over it, to allow of access during rain.

The Limnograph.—A detailed description of the Sarasin limnograph is not called for here. Its essential parts will be understood from the photograph reproduced in fig. 2. The modifications that were found necessary during our experiments will be explained in due course.

The Cylinder.—All the limnographs belonging to the Lake Survey were fitted with cylinders of 13½-inch inside diameter. This is probably somewhat excessive, and cylinders of 12 inches should be ample. The water is admitted to the cylinder by a circular opening, in which is fixed a short piece of brass tube, to which the long tube leading to the deep water can be attached. It is convenient to have this short piece of such a diameter that two standard sizes of rubber tubing can be easily and quickly connected with it. If it is made of 1-inch inside diameter, a ¾-inch rubber tube can be slipped inside it, or a 1-inch tube outside. Other sizes can be attached by using short connecting pieces of various diameters. It is needless, and in stormy weather objectionable, to have brass couplings which require to be screwed on.

The Long Tube.—The tube leading from the cylinder to the moderately deep water of the loch is an important part of the apparatus. It is designed to eliminate the effect of short waves. Lead tubing was first used; it was found difficult to lay this without bays in which air might accumulate, and it was discarded in favour of rubber hose-pipe. The length of pipe necessary varies with the local conditions. In Loch Earn, a length of 60 feet was sufficient to reach a depth of 10 feet or upwards, which was enough to purify the curve of disturbances peculiar to shallow water. The outer end of the tube, lying on the bottom of the loch, is apt to get choked with mud. This is prevented by passing the end of the tube through perforations in a cubical box, which in any position will keep the tube 1 foot or so off the bottom.

The ratio which the length and diameter of this tube should bear to the diameter of the cylinder is very important, and Professor CHRYSTAL made a number of calculations of what it ought to be in certain cases. These need not be entered into here, as we are only concerned with the practical manipulation of the apparatus. Following on Professor CHRYSTAL's calculations, a number of experiments were made with different sizes of tubes.

The aperture in the cylinder was plugged and a measured quantity of water introduced. Then, the plug being removed, the rate of leak through tubes of various diameter was timed. Defects of the Sarasin limnograph unfortunately rendered this experiment worthless.

We then attached 60 feet of ¾-inch lead tubing to the cylinder, and compared the seiche tracing obtained through this with one read simultaneously from an index limnograph. We thought we detected lag, and there was certainly damping of the seiche. We therefore adopted for both limnographs tubing of 1½-inch diameter. It was afterwards ascertained that the damping was due to back-lash and friction in the instrument. It was also found that when the ¾-inch tube was led into a 6-inch well, there was no perceptible lag. The ¾-inch tube with a 13½-inch well might cause some

lag; but there can be no doubt that 1-inch tubing would be ample for that size of well, and for any reasonable length, say up to 100 feet, and probably much more. More accurate experiments under favourable conditions are wanted.

Experiments made at a later period with smaller sizes of tubing, led into a 6-inch well, showed that a slight decrease of diameter increased the amount of lag, while a considerable increase of length had no perceptible effect (within the narrow limits of our experiments—20 feet of $\frac{1}{4}$-inch tube, for example, caused no visibly greater lag than 10 feet).

Float and Counterpoise.—Our experience shows that the counterpoise should be much lighter than the float. In the Sarasin limnographs as originally set up, the float and counterpoise were too nearly balanced. (This is no defect in the instruments, as the floats were not supplied with them but made in this country.) In practice the exact ratio of the weight of the float and counterpoise is not of vital importance, and we got satisfactory results with the float three or four times as heavy as the counterpoise. The essential thing is that they be not too nearly equal, and the float should be not less than twice the weight of the counterpoise.

When they are too nearly alike in weight, the effect of friction at the pulley bearings is increased. In instruments of this sort, in which the movements are extremely slow and gradual, it is inevitable that friction will give rise to slight retardation, and the record therefore proceeds by a series of minute steps. In the traces made by the Sarasin limnographs, before they were modified, the steps were very large. With the direct acting limnograph, and the weight and float bearing the proper ratio to one another, the jerks are so diminished as to be negligible, and are even as a rule quite imperceptible.

A large buoyant float is not desirable. The more buoyant the float, and the greater its height in proportion to its diameter, the greater is the tendency to wobble, whether from slight currents of air, or from vibrations of the water inside the cylinder, such as might be set up by the impact of the waves on its outside. A broad float, relatively low, and projecting as little as may be above the surface of the water, has been found best;—indeed, a completely water-logged piece of wood, which would not float at all without the assistance of the counterpoise, has given perfectly satisfactory results; it has the advantage of being free from capillary disturbance, as it is always wetted by the water.

Modification of Sarasin Limnographs.—From previous experience of the two Sarasin limnographs, when in use on Loch Ness and Loch Treig, it was not expected that they would give perfectly satisfactory work with the small seiches of Loch Earn. It was known that there was a good deal of back-lash in the apparatus for converting the vertical motion of the float into a horizontal motion of the pen. It was suspected that there was friction among the rods and tubes controlling the vertical motion. When previously used the limnographs were set up at the end of lochs, where the seiches are greatest—the damping from those defects being therefore less perceptible,

though it was known that at one time on Loch Treig the back-lash amounted to about 1 inch.

On Loch Earn, where the seiches are normally smaller, and where, moreover, the observations were made at the nodes, damping of the seiches was very noticeable—amounting, in fact, to the total obliteration of seiches of less than half an inch.

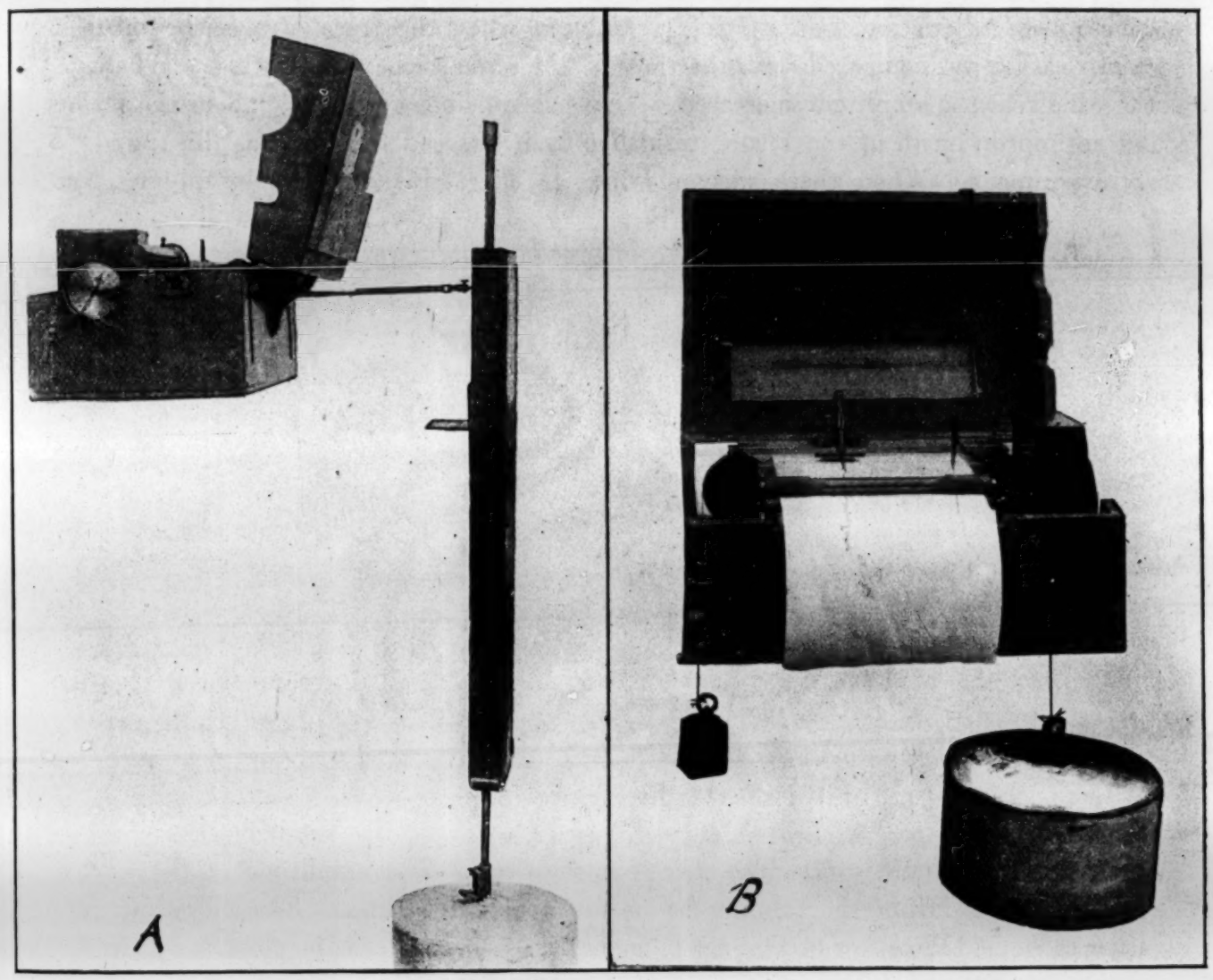


FIG. 21.—A: The Sarasin Limnograph in its original state, showing the outside parts which were removed. B: The same seen from the front, after modification, showing wire passing directly from float to counterpoise over the two pulleys.

The back-lash was the least serious difficulty; it could be minimised, to the extent of being negligible, by occasional overhauling and tightening of the Hookes joints. The friction of the vertical rod connected with the float, where it slides through two squared guides in an iron box, was found to be so serious that the whole apparatus had to be modified. It is only possible for the instrument to give passable results under the best possible conditions—when it is rigidly fixed in a permanent building, sheltered from damp, built absolutely vertical, and with the guides smoothed

and oiled. These conditions cannot be fulfilled when the instrument is set up on a temporary structure, inadequately protected from the weather. The vertical rod is of brass—it is square, and slides through two iron sockets slightly greater in diameter. These cannot act as guides unless there is contact of one side; and we thus have brass sliding on iron, which is apt to get rusty and cause very serious friction.

The extent to which the amplitude of the seiche was diminished on the trace in consequence of friction, was strikingly exhibited when the trace of a seiche taken in calm weather was compared with the trace of the same seiche during wind. Whenever the wind rose the amplitude increased. That this was not a real change in the seiche, but an improvement in the record resulting from reduced friction, was illustrated by an experiment. When there was no wind its effect was imitated by tapping con-

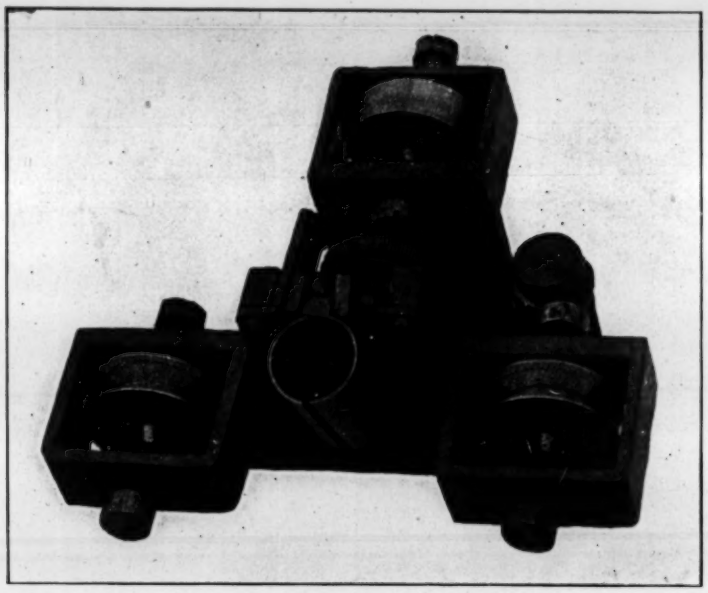


FIG. 22.—The M'Kinstry Waggon.

tinuously on the framework. The effect was the same. The amplitude of the seiche-trace increased during the tapping by as much as three times. The vibration from either cause had the effect of shaking momentarily free the parts in contact where the most serious friction occurred, and the trace gave the full amplitude, but in a series of jerks.

The portions of the limnograph, external to the recording box, are complex. There are so many joints that even under the best conditions there is some back-lash. It was resolved to do away with all this part of the apparatus altogether; and to render the instrument direct acting by taking a line over the pulleys, and bringing the cylinder right under one pulley, so that the float would hang free under the pulley. The triple steel wire used for the Pullar sounding machines was used as the driving line. Grooves to accommodate the wire were turned in the two pulleys.

The limnograph in its altered state was a much more useful instrument, and for the first time began to record seiches of the full amplitude. Further alterations were afterwards made. The travelling rod which carries the pen in the Sarasin limnograph was not so satisfactory after the machine was rendered direct acting. The construction of the metal framework required the driving wire to pass over both pulleys, either of which might at any moment take the lead. The resultant "quarrel" might cause jerks. The defect was perhaps mainly hypothetical, and might have no real existence if the two pulleys were precisely alike in diameter; nevertheless, it was desirable to remove even hypothetical defects, and a further change was made.

Professor CHRYSTAL had had a new limnograph made by Baird of Edinburgh, which was also direct acting, and had as a special feature the carrying of the pen by a little waggon which ran by means of three wheels on a pair of rails.

It was decided to adapt the railway and waggon to the Sarasin limnographs. An improved form of waggon, more convenient to attach and detach, was made by Mr M'Kinstry of Comrie, and proved very successful in use.

The waggon and clip for holding the pen are shown in fig. 22.

THE INDEX LIMNOGRAPHS.

The first two portable limnographs constructed for Professor CHRYSTAL were found to work admirably. They were, however, somewhat inconvenient to set up, and they were too large to be easily portable on bicycles. To obviate these objections, much smaller and lighter instruments were made after my design, which could be carried about without difficulty. The form finally adopted is shown in the accompanying photograph (fig. 23).

The essential parts of the instrument are the float and counterpoise, connected by a line which passes over a vertical pulley; a pointer attached to the pulley or to its axle; a scale on which the movements of the pointer can be read; a well for the float, and a syphon connecting the well with the lake. The whole apparatus is supported by an ordinary camera tripod.

The Float.—A circular disc of hard wood, 4 inches in diameter by $\frac{1}{2}$ inch thick, was found sufficient. When water-logged, this was very little affected by the wind. Hollow zinc floats were first used, but they were too unsteady if any wind was blowing.

The Line.—Fine waterproofed fishing-line was used. We were unable to ascertain whether the line stretched and contracted much with varying degrees of moisture and temperature. In the course of an observation it was commonly the case that the mean level steadily rose or fell; more rarely it would rise for a time, then fall again, or *vice versâ*. These changes could be caused by changes in the length of the line, or they might be real changes in the level of the loch. When the index was used close to a permanent limnograph, both instruments usually indicated the same changes of level, showing that these were really occurring in the loch.

The Counterpoise.—This need not be more than a few ounces in weight. In form it should be narrowly cylindrical, so as to offer little resistance to the wind. Some serviceable weights were made by twisting small coils of lead wire.

The Pulley.—A pulley of 2 inches diameter was taken as the standard. A groove served to keep the line in place; the diameter of the pulley was measured from the bottom of the groove. A steel axle rested on brass or steel bearings. The first instrument made had friction wheels as bearings, which allowed the pulley to work with great

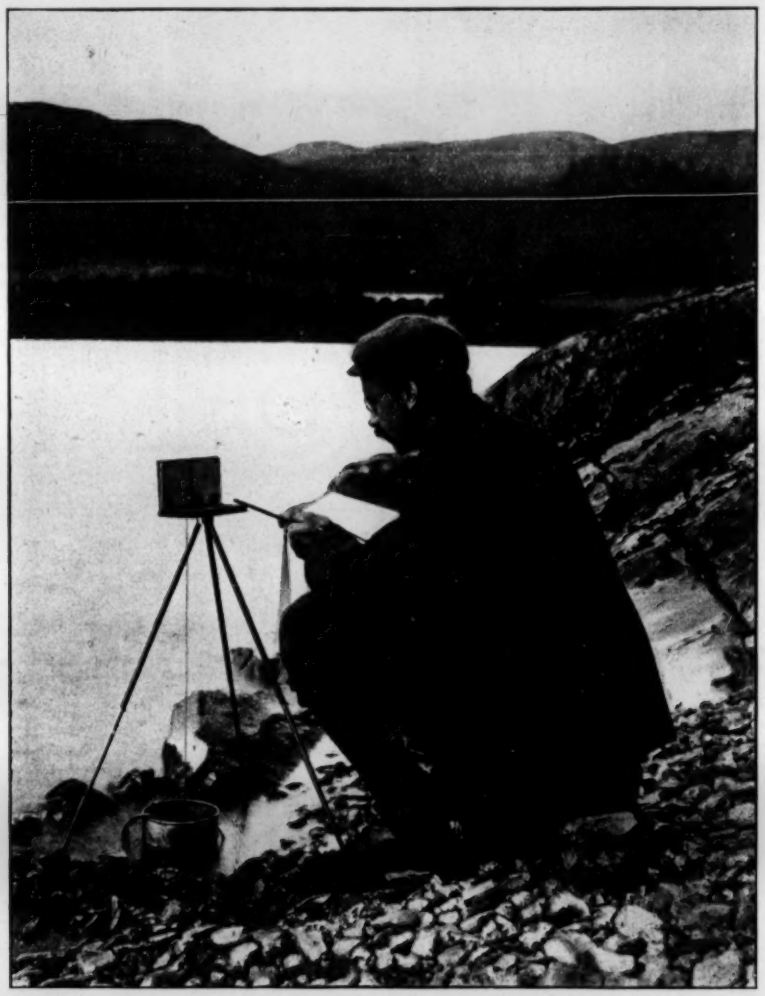


FIG. 23.—Mr A. Fraser using the Index Limnograph.

freedom. Some of the other instruments had rather broad bearings, and there was considerable friction; this was counteracted in practice by tapping the stand very lightly with a pencil before taking the reading. If the bearings were made sharp enough, however, the friction was so little that the tapping was unnecessary. In one instrument, hurriedly constructed in the field, the bearings were simply a pair of brass hinges, the ends of the axle resting in the nail holes. In this we could detect no retardation whatever, due to friction; the pulley appeared to turn as freely as on friction wheels.

The pulley was supported on a horizontal board, perforated to receive it. Another board, intended to hold the scale, was hinged to this at right angles; it was hinged in such a position that it could not open beyond the right angle. In this position it was maintained by a rubber band. When not in use the two boards were folded together, and enclosed the pulley and pointer between them.

Index and Scale.—Whatever size of pulley was used, the Index or Pointer was made equal to four times the radius; or the scale was so constructed as to indicate the values at four times the radial distance, which comes to the same thing in practice. There was thus an exaggeration of the seiches by four times, which made the smaller ones easy to read. The scale was divided into inches and tenths of an inch. By using paper also ruled in inches and tenths, the curves when plotted had exactly four times the amplitude of the seiches.

The Tripod.—Several camera-stands were tried. That found most convenient was a light brass tubular telescopic tripod, the three legs fixed at the top to a circular plate, which was joined to the table by a few turns of a single screw. It could be extended to a length of 4 feet 6 inches, but was never used at more than 3 feet.

The Well.—A very important part of the apparatus, and one which needed a good deal of experimenting before it was brought to a satisfactory state. In calm weather the tripod could be set up and the float placed directly in the loch, without any protection. This was, however, rarely possible, and we invariably used a zinc or tin cylinder. A cylinder of 6-inch diameter was the smallest that would accommodate our little floats and the syphon tube, leaving sufficient room for free motion. Ordinary milk-cans supplied all that we desired.

At first the water was admitted to the cylinder by a few small perforations in the bottom, or low down at the sides. This did well enough, but had the disadvantage that we did not know exactly what we were doing—we could not calculate the relation of adit to water surface in the well. The method was soon abandoned for the syphon, which was continuously used afterwards. The pail could be placed in the loch, but it was there liable to disturbance if the wind rose; and it was usual to put it in a larger well, either completely cut off from the loch, or partly in connection with it and protected by a breakwater.

A large well, having free communication with the loch, was best. If the ingress and egress of the water is not free enough, the breaking of the waves tends to keep the well at a higher level than the loch and to float the cylinder. The same difficulty occurs in another way when the well is quite isolated. The water percolating through the sand raises the well above the level of the loch; this was more marked if large waves were breaking and saturating the soil around, though they might not enter the well. The trouble from this cause was so frequent that we habitually weighted the cylinders. If flat stones of the right size could be found, they were used; if not, a layer of sand or small gravel. The cylinder was also steadied outside by stones to prevent the wind or the waves from moving it.

The Syphon.—Two sizes of red rubber tubing were employed—one of $\frac{1}{2}$-inch inside diameter in fine weather, when we wished to observe as many of the seiches as possible; one of $\frac{1}{4}$-inch diameter, when we wished to eliminate the smaller seiches or the surface swell. The syphon was filled in the loch;—the larger size of tube could be stopped by inserting the finger till the end was moved into the pail—the smaller one by a lead-pencil. After the syphon was in place, it was usual to fill the pail considerably above the surface of the loch in order to test whether the syphon were working.

Method of using Index.—After the apparatus was set up, and it had been ascertained that the syphon was working properly, a little time was allowed for the water in the well to adjust itself to the level of the lake before beginning the observation. Readings were taken every half-minute. A large, fairly pure seiche could be accurately enough plotted from readings taken at intervals of one minute. This interval was found to be much more trying to the observer than a shorter one, and there was even a greater liability to error; the longer interval was too sustained a strain on the attention. Readings were sometimes taken at shorter intervals (every quarter-minute) when it was desired to measure the smaller seiches.

At first all the readings were noted down in figures, and the curves were afterwards plotted, and in wet weather this continued to be the method adopted. In dry weather the curves were plotted directly on to the squared paper, a dot being made for each reading. A great saving of labour was thus effected, and there was the further advantage that one could readily see, after a few minutes' work, whether there was enough seiche to make it worth while to continue.

When well-marked short seiches occurred along with larger ones, the larger seiches could not be accurately traced by the index readings. The half-minute readings might be sometimes at the maximum and sometimes at the minimum of the shorter seiches, and so the curve was rendered irregular. If it was desired to read both the long and the short seiches, an attempt was made to watch for the turning-points of the shorter seiche, whether they occurred at the half-minute readings or between them; but as the eye had to be momentarily removed from the index, in order to plot each point as read, the maxima and minima were apt to be missed.

All need to attempt to read very small seiches was removed by Professor CHRYSTAL's adaptation of the statoscope as a limnograph (see Professor CHRYSTAL's paper, p. 367).

It then became the custom to cut out the smaller seiches by using narrower syphons ($\frac{1}{4}$ inch). When this was done a certain amount of lag was introduced, which had to be measured and corrections made before the curve could be compared with that of the Sarasin limnograph.

In the carrying out of these observations and experiments, Mr Archibald Fraser, who was engaged from first to last, was of invaluable assistance. He offered many useful suggestions for the improvement of the instruments, and made many excellent observations with the index limnographs. Mr Fraser is shown in fig. 23 taking an observation.

XV.—The Viscosity of Solutions. By C. Ranken, B.Sc., Carnegie Research Scholar, and Dr W. W. Taylor. Part I. *Communicated by* Professor Crum Brown.

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In a recent paper * published by the authors, some measurements of the viscosity of aqueous solutions indicated that it would be of interest to investigate more fully the viscosity of solutions, especially those which exhibit what is now generally known as "negative viscosity," over a wider range of temperature.

This has now been done to a certain extent, and to enable a comparison to be made between electrolytes and non-electrolytes in aqueous solution, some other substances have been included in the investigation. They are:—potassium chloride, potassium chlorate, ammonium iodide, potassium ferricyanide, potassium ferrocyanide; mercuric chloride, mercuric cyanide; carbamide.

Method and Apparatus.

In the determination of relative viscosity by Ostwald's method (Ostwald-Luther, *Phys. chem. Messungen*, p. 260) there are two, if not three, points which require special attention, in addition to the usual precautions to ensure constant temperatures, etc. These special features are:—the cleaning of the capillary tube, the constancy of the volume of liquid introduced into the viscosity tube, and the measurement of the time interval which the liquid takes in flowing from the one mark to the other. The last is the most difficult to deal with, and, in order to minimise the error, the dimensions of the tube are often so adjusted by means of a very fine capillary, or of a bulb containing a comparatively large volume of liquid, that the time of flow is very long. Each of these devices is open to serious objections, and, as our previous experience had convinced us of the inherent unreliability of ordinary stop-watches, and especially of the impossibility of starting or stopping them at the precise instant, we adopted a different method of time measurement which has been found to be convenient and accurate to a high degree.

An electromagnetic clock with half-second pendulum electrically records seconds, or other intervals of time up to one minute, on a band of smoked paper. This band of paper is about 3 metres in length, and runs over two drums, one large and one small, the large one being driven at an approximately constant speed by an electric motor; the speed is reduced and adjusted by means of a worm reducing-gear. An electromagnetic time-marker records the experimental times on the paper immediately

* *Proc. Roy. Soc. Edin.*, 25, p. 231, 1904.

below the clock record. In most of our experiments the speed of the paper was so adjusted that 15–20 millimetres corresponded to an interval of one second.*

As the determinations of the corresponding times of flow for the solvent and the solution were always made on the same day, errors due to variation of the rate of the clock were to a large extent eliminated.

The following consecutive determinations of the time of flow of a volume of liquid will give some idea of the accuracy attained :—

(1) Water, 166·95, 166·93, 166·96 seconds.
(2) Solution of carbamide, 157·77, 157·84, 157·78 seconds.
(3) Water (30°), 206·50, 206·55, 206·30, 206·42, 206·43 seconds; mean, 206·45 seconds.

No. (3) is given as an example of the extreme variation observed. In such cases the experimenter is often aware that he has missed the precise moment; but, as in the above set, exclusion of the lowest, or of the two extremes, has practically no effect on the mean value.

Before each experiment the viscosity tubes were cleaned with chromic acid mixture and thoroughly washed with distilled water. In order to avoid the use of alcohol and ether, the tubes were dried by connecting them with an electrically-driven Geryk pump, the air being passed through cylinders with calcium chloride, phosphoric anhydride, and cotton wool before being admitted to the tube. If, on repetition, the results were not found to be concordant, it was generally found that the discrepancy disappeared after the tube had been recleaned.

The degree of accuracy attainable in introducing the same volume of liquid into the viscosity tube was also carefully inquired into. This was necessary, for it seemed probable that the volume of liquid delivered by the same pipette might be different for the solvent and the solution, and for different concentrations of the solution, owing to the differences in viscosity of the liquids.

In the test experiments the viscosity tube was weighed before and after the addition of the solvent and of the solution, and the weights of liquid were compared with their densities as determined in the usual manner.

(1) 15° C. H_2O, (*a*) 2·1412 gm.; (*b*) 2·1416 gm.; (*c*) 2·1410 gm.
(2) 25° C. H_2O, (*a*) 2·7215 gm.; (*b*) 2·7201 gm.
·05 m. KCl, (*a*) 2·7247 gm.; (*b*) 2·7262 gm.
$d\ 25°/4° = 0·9988$, instead of 0·9993.
(3) 15° C. H_2O, (*a*) 2·7239 gm.; (*b*) 2·7222 gm.
·25 m. KCl, (*a*) 2·7560 gm.; (*b*) 2·7568 gm.
$d\ 15°/4° = 1·0114$, instead of 1·0112.

It may be taken that the volume delivered was constant to within 1 in 2000.

In conclusion, a few actual experiments are appended, which were made on totally

* [This form of electric chronograph, which is commonly used in physiological laboratories, is very convenient for physico-chemical purposes; for, if required, it can make a large number of independent experimental records simultaneously, without alteration of the apparatus beyond an additional number of electromagnetic time-markers, which are small and inexpensive. The apparatus was made for us by J. Ednie, mechanic in the Physiology Department, Edinburgh University.]

independent solutions of the same substance; and from them the limits of variation in the value of the viscosity may be ascertained.

(1) 25° C. ·1 m. KCl.

(*a*) Nov. 22, 1905.

Water . . .	97·50 sec.	$\eta/\eta_0 = 1{\cdot}0002$.
Solution . . .	97·05 ,,	

(*b*) Jan. 31, 1906.

Water . . .	206·06 sec.	$\eta/\eta_0 = 0{\cdot}9996$.
Solution . . .	204·96 ,,	

Two different viscosity tubes were used in this case.

(2) 8° C. ·03125 m. carbamide.

(*a*) June 14, 1906.

Water . . .	152·84 sec.	$\eta/\eta_0 = 0{\cdot}9987$.
Solution . . .	152·57 ,,	

(*b*) June 18, 1906.

Water . . .	152·84 sec.	
Solution . . .	152·55 ,,	$\eta/\eta_0 = 0{\cdot}9985$.

The tubes employed by us, up to the present, are all of the Ostwald pattern (as figured in Ostwald-Luther's *Phys. chem. Messungen*, p. 260). The difference of time of outflow is not caused to any considerable extent by differences in length or diameter of the capillary, but is due to the fact that the bulbs immediately above the capillary were of different capacities, and, indeed, were generally adjusted so as to give a suitable time of outflow.

The diameters of the two capillary tubes were measured, and were found to be as follows:—

(1) Greatest diameter, 0·56 mm.; least diameter, 0·50 mm.
(2) ,, ,, 0·60 mm.; ,, ,, 0·52 mm.

The pycnometers with which the density determinations were made were of about 13 c.cm. capacity. The solutions and the water were carefully freed from air, and the temperatures at which the adjustments of the volumes in the pycnometer were made were extremely constant. The densities of the solutions may be taken to be accurate to 1 in 10,000. The densities of water at the different temperatures were the values given in the table of Thiesen, Scheel, and Diesselhorst (in Ostwald-Luther's *Phys. chem. Messungen*, p. 128). The relative viscosity was calculated by means of the formula

$$\eta/\eta' = dt/d't',$$

and not from the more accurate formula

$$\eta/\eta_1 = (d - \lambda)t/(d' - \lambda)t',$$

as the density of the air (λ) would not introduce an error greater than 1 in 10,000, and may therefore be neglected.

Experimental Results.

In the following tables

η_0 is the viscosity, expressed in absolute units, of water at the given temperature. The values of η_0 are taken from Thorpe and Rodger's determinations.*

m is the concentration of the solution in mols per litre.

d is the density of the solution referred to water at 4°.

η/η_0 is the ratio of the viscosity of the solution to that of the solvent at the given temperature, as directly determined by experiment.

η is the viscosity of the solutions in absolute units, and is obtained from the ratio given in the third column by multiplication with the value of η_0 given at the head of the table.

Potassium Chloride.

15° C.

$\eta_0 = \cdot011335$.

m	d	η/η_0	η
1	1·0456	·9695	·01099
·5	1·0227	·9822	·01113
·25	1·0112	·9890	·01121
·2	1·0087	·9925	·01125
·125	1·0052	·9953	·01128
·1	1·0040	·9965	·011295
·0625	1·0022	·9970	·01130
·0500	1·0014	·9982	·011315

25° C.

$\eta_0 = \cdot00891$.

m	d	η/η_0	η
1	1·0428	0·9935	·00885
·5	1·0201	·9940	·00886
·25	1·0087	·9967	·00888
·2	1·0064	·9985	·008895
·125	1·0029	·9989	·00890
·1	1·0017	1·0000	·00891
·0625	1·0000	·9990	·00890
·05	0·9993	·9995	·008905

30° C.

$\eta_0 = \cdot007975$.

m	d	η/η_0	η
1	1·0411	1·0057	·00802
·5	1·0187	1·0008	·00798
·25	1·0073	1·0005	·007978

35° C.

$\eta_0 = \cdot00720$.

m	d	η/η_0	η
1	1·0393	1·0160	·007315
·5	1·0170	1·0082	·00726
·25	1·0057	1·0048	·007235

45° C.

$\eta_0 = \cdot00597$.

m	d	η/η_0	η
1	1·0357	1·0312	·006155
·5	1·0127	1·0150	·006059
·25	1·0021	1·0080	·006018
·1	·9950	1·0032	·005989

* *Phil. Trans.*, 185, p. 449, 1894.

MERCURIC CYANIDE.

15° C.

$\eta_0 = \cdot011335$.

m	d	η/η_0	η
·25	1·0479	1·0361	·01174
·125	1·0234	1·0178	·01154
·0625	1·0112	1·0103	·01145

35° C.

$\eta_0 = \cdot00720$.

m	d	η/η_0	η
·25	1·0433	1·0330	·00744
·125	1·0181	1·0167	·00732
·0625	1·0061	1·0089	·00726

25° C.

$\eta_0 = \cdot00891$.

m	d	η/η_0	η
·25	1·0454	1·0345	·00922
·125	1·0213	1·0175	·00907
·0625	1·0092	1·0092	·00899

45° C.

$\eta_0 = \cdot00597$.

m	d	η/η_0	η
·25	1·0384	1·0310	·006155
·125	1·0146	1·0150	·006069
·0625	1·0024	1·0076	·006015

MERCURIC CHLORIDE.

15° C.

$\eta_0 = \cdot011335$.

m	d	η/η_0	η
·125	1·0286	1·0142	·01152
·0625	1·0137	1·0095	·01146
·03125	1·0063	1·0042	·011395

25° C.

$\eta_0 = \cdot00891$.

m	d	η/η_0	η
·125	1·0263	1·0165	·00906
·0625	1·0118	1·0107	·009005
·03125	1·0043	1·0053	·00896

POTASSIUM FERRICYANIDE.

1·6° C.

$\eta_0 = \cdot01683$.

m	d	η/η_0	η
·25	1·0458	·9905	·01667
·125	1·0231	·9868	·01661
·0625	1·0117	·9918	·01668

15° C.

$\eta_0 = \cdot011335$.

m	d	η/η_0	η
·5	1·0854	1·0703	·01213
·25	1·0428	1·0227	·01159
·125	1·0214	1·0100	·01145

25° C.

$\eta_0 = \cdot00891$.

m	d	η/η_0	η
·5	1·0827	1·1085	·00988
·25	1·0407	1·0465	·00932
·125	1·0190	1·0208	·009095

Potassium Ferrocyanide.

15° C. $\eta_0 = \cdot011335$.

m	d	η/η_0	η
·5	1·1164	1·2206	·01384
·25	1·0595	1·0947	·01241
·125	1·0299	1·0470	·01187

25° C. $\eta_0 = \cdot00891$.

m	d	η/η_0	η
·5	1·1128	1·2575	·01120
·25	1·0564	1·1173	·00996
·125	1·0273	1·0593	·00944

Potassium Chlorate.

15° C. $\eta_0 = \cdot011335$.

m	d	η/η_0	η
·25	1·0184	·9880	·01120
·125	1·0088	·9923	·01125
·0625	1·0039	·9958	·01129

30° C. $\eta_0 = \cdot007975$.

m	d	η/η_0	η
·333	1·0208	1·0000	·007975
·25	1·0146	·9980	·00796
·125	1·0052	·9985	·007965
·0625	1·0006	·9995	·00797

25° C. $\eta_0 = \cdot00891$.

m	d	η/η_0	η
·333	1·0223	·9937	·00885
·25	1·0160	·9980	·00889
·125	1·0065	·9990	·00890
·0625	1·0017	1·0005	·008915

35° C. $\eta_0 = \cdot00720$.

m	d	η/η_0	η
·333	1·0189	1·0010	·00721
·25	1·0128	1·0002	·00720
·125	1·0035	·9989	·00719
·0625	·9988	1·0000	·00720

45° C. $\eta_0 = \cdot00597$.

m	d	η/η_0	η
·25	1·0088	1·0045	·005997
·125	0·9998	1·0023	·005985
·0625	0·9952	1·0018	·00598

Ammonium Iodide.

30° C. $\eta_0 = \cdot007975$.

m	d	η/η_0	η
6	1·5285	1·0315	·00823
4	1·3513	·9137	·00729
1	1·0944	·9446	·00753
·5	1·0401	·9705	·00774
·25	1·0181	·9860	·00786
·125	1·0071	·9930	·00792

45° C. $\eta_0 = \cdot00597$.

m	d	η/η_0	η
1	1·0853	·9682	·005780
·5	1·0380	·9810	·005855
·25	1·0145	·9925	·005925
·125	1·0026	·9968	·005950

CARBAMIDE.

8° C.

$\eta_0 = \cdot 013895$.

m	d	η/η_0	η
0·125	1·0020	1·0012	·01391
·03125	1·0004	·9985	·01387

30° C.

$\eta_0 = \cdot 007975$.

m	d	η/η_0	η
1	1·0115	1·0443	·00833
·5	1·0037	1·0210	·00814
·25	·9999	1·0113	·008065

15° C.

$\eta_0 = \cdot 011335$.

m	d	η/η_0	η
1	1·0156	1·0325	·01170
·5	1·0074	1·0150	·011505
·25	1·0032	1·0085	·01143

35° C.

$\eta_0 = \cdot 00720$.

m	d	η/η_0	η
1	1·0094	1·0448	·00752
·5	1·0019	1·0232	·00737
·25	·9991	1·0120	·00729

25° C.

$\eta_0 = \cdot 00891$.

m	d	η/η_0	η
·125	·99906	1·0050	·008955
·03125	·99754	1·0020	·00893

45° C.

$\eta_0 = \cdot 00597$.

m	d	η/η_0	η
1	1·0054	1·0488	·00626
·5	·9978	1·0241	·00611
·25	·9942	1·0124	·00604

AMMONIUM IODIDE

in a solution of $KClO_3$, for which $\eta/\eta_0 = 1$ at 30° C.

30° C.

$\eta_0 = \cdot 007975$.

$m(NH_4I)$	η/η_0	η
1	·9464	·00755
·5	·9710	·00774
·25	·9853	·00786
·125	·9935	·00792

CARBAMIDE

in a solution of $KClO_3$, for which $\eta/\eta_0 = 1$ at 30° C.

30° C.

$m(CO(NH_2)_2)$	η/η_0	η
1	1·0462	·00834
·5	1·0218	·00815
·25	1·0113	·008065

Discussion of the Results.

1. *The relation between concentration and relative viscosity.*—The previous determinations of the relative viscosity of potassium chloride solutions were insufficient to show conclusively the nature of the curves below concentrations of 1 mol per litre. It was obvious, however, that below that concentration the curves which were practically straight lines must change their character, since the line did not pass through the origin at zero concentration. Whether the viscosity of the solution at some finite concentration became the same as that of water below which concentration it was less than that of water (so-called "negative viscosity"), finally at infinite dilution to again become the same as that of the solvent, could not be settled. Our present results indicate that the course of the curve is somewhat complicated. At 25° C. at concentrations between 1 mol and 2 mols per litre, the value of η/η_0 is greater than 1, at 1 mol per litre it is less than 1, but steadily increases with increasing dilution until at 0·1 mol per litre the ratio is again $= 1$; after which it is probably a little less than 1, the observed values being ·9990 and ·9995.

2. The results obtained for potassium chloride were recalculated and curves drawn to show the relation of the ratio η/η_0 to the concentration of the solution expressed in mols per kilogram of solution, to the number of mols of solvent to one mol of solute, and to the number of mols of solution to one mol of solute, but none of these methods of representation introduced any simplification of the curve.

3. In all the solutions examined, with the one exception of mercuric cyanide, increase of temperature increases the ratio η/η_0. For electrolytes the rate of increase is very much greater than for non-electrolytes; mercuric chloride, which is very little ionised, ranges itself with the non-electrolytes in this respect also.

At high temperatures solutions of mercuric cyanide might be expected to exhibit "negative viscosity," but at 45° C. the ratio η/η_0 is still distinctly greater than unity, the temperature-coefficient being very nearly the same as for water.

4. Our measurements give further support to the view that the relative viscosity of all solutions passes through at least one minimum, the position of the minimum being determined by the nature of the substance and the temperature. The minimum value may be smaller than the corresponding value for the solvent. Whether this occurs or not depends on some factor yet unrecognised.

5. *Carbamide.*—Rudorf * found that, at 25° C., the relative viscosity of aqueous solutions of carbamide decreased with dilution, and at concentrations below ·234 mol per litre became less than that of water; the values are—

m	η/η_0
0·937	1·010
·469	1·002
·234	·996
·117	·993
·058	·995

* *Zeit. f. Phys. Chem.*, 43, p. 257, 1903.

FAWSITT* was unable to confirm these results of RUDORF, and did not obtain any evidence of "negative viscosity" at any concentration. Our measurements, while not in close agreement with FAWSITT's results, also give no indication of "negative viscosity" at 25° C., the values of η/η_0 being 1·005 for 0·125 m. solutions, and 1·002 for 0·03125 m. solutions.

When determinations were made at 8° C., the ratio became slightly less than 1, but only in the case of the most dilute solution. The ratio η/η_0 for a concentration of 0·03125 mol per litre is 0·9985. This value, and also all the other data for carbamide solutions, have been repeatedly determined with independent solutions, and with two different samples of carbamide, and though it is so nearly equal to 1, it is certainly less than 1. The "negative viscosity" would probably be more pronounced at lower temperatures.

Hitherto the only exception to the general rule that aqueous solutions of electrolytes alone exhibit "negative viscosity" has been the fact, established by MÜHLENBEIN and WAGNER,† that some organic substances in organic solvents, *e.g.* cyanobenzol in ethyl alcohol, also exhibit it. Aqueous solutions of carbamide have now been shown to do the same. Other substances may also do so at low temperatures, whilst, as already mentioned, mercuric cyanide may be expected to do so at high temperatures.

6. It seemed probable that a comparison of the viscosity-effect of adding equivalent quantities of an electrolyte, and of a non-electrolyte, to water on the one hand, and to an aqueous solution which at the temperature of experiment has the same relative viscosity as water ($\eta/\eta_0 = 1$), might yield interesting results.

Accordingly, a large quantity of solution of potassium chlorate was made up (approximate concentration ·3 mol per litre) which at 30° C. had the relative viscosity 0·998. This substance was chosen because slight variation in the concentration has very little effect on η, nor does η/η_0 change to any great extent with change of temperature; the necessary concentration, also, is not great.

It was necessary to select a salt which has no ion in common with potassium chlorate, so as to avoid alterations in ionisation, etc.; ammonium iodide fulfils this condition; carbamide was used as a non-electrolyte which does not react with the chlorate.

The results obtained show that when the amount of solute added is small there is no recognisable difference between the pure water and the chlorate solution. When the amount of solute added reaches 1 mol per litre there is a slight but distinct difference in both cases; this is probably mainly due to the fact that the ratio of the number of molecules of water to those of ammonium iodide or carbamide becomes more widely different when the number of molecules of the solute is great.

This difference is in the same direction and approximately to the same extent with both solutes. These experiments do not throw much light on the question of the

* *Proc. Roy. Soc. Edin.*, 25, p. 52, 1904.
† *Zeit. f. Phys. Chem.*, 46, p. 872, 1903.

combination of solvent with solute, but, if such combination takes place, one might expect that the viscosity of water and of a solution of potassium chlorate would be altered to an appreciably different extent by addition of an indifferent solute, which also enters into combination with the solvent.

We are at present engaged in an investigation of the comparative effect of certain solutes on the viscosity of different solvents, the comparison being made on the basis of the number of molecules of the solute per volume of solution, and of the number of molecules of the solute to molecules of solvent. In this way it is hoped some light may be thrown on the nature of the effect of solute on solvent, and the alteration of the effect with the nature of the solvent.

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XVI.—The Temperature of the Fresh-water Lochs of Scotland, with special reference to Loch Ness. With Appendix containing Observations made in Loch Ness by Members of the Scottish Lake Survey.

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I. INTRODUCTORY.

My object in this paper is not, as the title might suggest, to give a comparative study of the fresh-water lochs of Scotland from the point of view of temperature. I had hoped at one time that this would be possible, and I may again return to this part of the subject of lake temperatures; but the more I have considered the question the more am I convinced that such a comparative study from the observations at my disposal would be based on assumptions too fundamental and too uncertain to make the conclusions reached of any great value. Consider the factors which go to produce variations of temperature as they are given by Professor FOREL.* Briefly, these are the indirect action of the sun in heating up the atmosphere and the surroundings of the loch, radiation from the loch, the effect of warm or cold water brought into the loch by rivers and by rain. These are only a few of the more important factors which are mentioned by FOREL, but I think that anyone considering these factors will perceive how slender the ground for any general conclusions must be. There is comparatively little object in comparing lochs which are at any great distance from one another, for the heating of a loch depends very largely on local conditions. One may be sheltered from all storms by surrounding hills, while another may be in a wind-swept region. One may be so overshadowed that very little direct sunlight falls on its waters, while another loch close by may get all the sunshine which it is possible to get. One may be fed by a large stream and have a considerable outflow, while another may be comparatively stagnant. One may be at a considerable altitude, while another may be in a warm valley. There is also, I think, little to be gained from a simple comparison of lochs close to one another, and which may appear at the first glance to be under similar conditions. For example, take some of the lochs in the Tay basin. In the hope of obtaining some satisfactory data I turned to Lochs Craiglush, Lowes, Butterstone, Clunie, etc.† These are at least sufficiently close to one another. They were surveyed in the month of June by members of the Lake Survey within a few days of one another, and temperature observations were also made in them. I then roughly

* *Le Léman*, vol. ii. p. 289.

† See *Geographical Journal*, January 1904, for the Lake Survey report upon these lochs.

calculated the mean temperature for the lochs from these observations. The following table shows the data for these lochs :—

Loch.	Mean Depth in Feet.	Volume in Million Cubic Feet.	Area in Square Miles.	Height above Sea-level in Feet.	Mean Temp.* Degrees Fahrenheit.
Craiglush . .	16	49	·11	328	50°
Lowes . . .	20	194	·34	328	53°
Butterstone . .	11	53	·17	314	58°
Clunie . . .	29	170	·21	156	51°

It will thus be seen that there is no obvious relation between the mean temperature and the other data for a loch. I have very little doubt that in this case the most important factor is that the first three of these lochs all drain into one another; and so we have the warm water of one loch draining into the next loch and there getting further heated up before passing on, and so forth. Clunie is not in the same string as the first three lochs, but is at a much lower level. Though it is considerably larger than Loch Craiglush in every respect, yet it is actually of a higher mean temperature. These lochs were chosen merely as examples to show how difficult it is, in the absence of the most complete meteorological and geographical information, to arrive at any exact conclusions.

There are difficulties of even graver importance. I have so far assumed that the observations from which I have arrived at the mean temperature of the lochs are sufficient for this purpose, and doubtless they are in the case of small lochs such as those already referred to. But this is by no means so in the case of the larger lochs. Sir John Murray † and Mr Fred P. Pullar have pointed out how impossible it is to deduce the temperature of the surface water from an isolated observation or from observations in one part of the loch. From what follows it will appear that not only is it impossible to tell anything of the surface temperatures of one part of a loch from observations made in another part, but also how it is in a far greater degree impossible to deduce the average temperature of a large loch from observations made in any one place, or even from observations made in different parts of the loch if they are made at different times. Before any satisfactory comparison of the temperature of the larger lochs of Scotland is possible, a more detailed thermometrical survey will be necessary. In Loch Morar, for instance, a number of observations were made at intervals for the purpose of such a comparison; but it was later realised that such isolated observations as were made were futile, and the observations were discontinued. The importance of the fact that observations in one part of a loch are not typical of the temperature of the loch as a whole has not, I think, been sufficiently grasped by

* Unless otherwise stated, the temperature scale is always Fahrenheit.

† *Geographical Journal*, April 1900.

other observers; and in view of the results which have been obtained by the Lake Survey, much of the work which has been done in observing lake temperatures will, I believe, prove to be of much less value than was hoped.

I had thought at first to discover some definite relation between the measurements of a loch and the quantity of heat stored up in it. Doubtless such a relation does exist of the same nature as is suggested by Sir JOHN MURRAY and Mr PULLAR.* Take, for example, Loch Leven and the Loch of Forfar,† which in the month of June had a somewhat similar mean temperature, viz., 54·0° F. Data for these lochs are given in the following table:—

Loch.	Volume in Million Cubic Feet.	Area in Square Miles.	Height above Sea-level in Feet.	$\frac{\text{Volume}}{\text{Area}}$.
Leven . . .	2195	5·30	22	11·2
Forfar . . .	51	·16	166	11·4

From these figures it seems that some relation might be discoverable between the temperature of the loch and the ratio of volume to area, but it is in general so obscured by varying factors that its disentanglement would entail an amount of labour which at present I consider disproportionate to the value of the results obtainable.

What I wish to do in the present paper is to give what I consider to be the history of the manner in which a loch gains and loses heat throughout the year; and though my deductions are based almost entirely on observations made in Loch Ness, yet I think that most of what there is to say of the temperature of Loch Ness will be found to be applicable to other lochs.

This paper is based on observations made by members of the Lake Survey,‡ with which for a time I had the good fortune to be associated. The material which has been collected is of a unique kind. In many lochs there have been observations lasting over a greater length of time, but in no case that has come to my knowledge has there been so continuous a series of observations. The regular temperature observations were begun by myself, in July 1903, by the establishment of a Lake Survey station at Fort Augustus. At first the observations were made by means of the deep-sea reversing thermometers, which are now so well known as to need no description here. The Pullar and Lucas sounding machines were both used in connection with these thermometers. Regular routine observations were soon begun at Fort Augustus, and a number of cruises were made along the loch in the steam

* *Geographical Journal*, March 1901. † *Geographical Journal*, January 1904.

‡ The observations were carried out by Sir JOHN MURRAY, Dr T. N. JOHNSTON, Mr R. C. MARSHALL, Mr JAMES MURRAY, Mr E. R. WATSON, Mr E. M. WEDDERBURN, and Mr F. G. PEARCEY, under the direction of Sir JOHN MURRAY, K.C.B., and Mr LAURENCE PULLAR. Valuable observations were also made by the Lake Survey boatmen, PHILIP CAMPBELL, FRASER, GRANT, and M'DONALD.

launch *Sunbeam*, taking series of temperatures at various points *en route* with the primary object of determining the temperature distribution of the loch and the direction of the isotherms, with reference to the effect of winds. Towards the middle of September a small decked fishing-boat was anchored off Fort Augustus in 250 feet of water. This yacht, which was christened the *Rhoda*, was fitted out specially for the observation of temperature by electrical means. In the boathouse of the Abbey at Fort Augustus, which was put at the disposal of Sir John Murray for this and other purposes, there was installed a Callendar electrical Recorder. This recorder was connected with the *Rhoda* by means of a cable consisting of four insulated wires as leads for the platinum resistance thermometers, which were operated from this boat. These thermometers could be lowered to any desired depth and then connected with the recorder on shore by means of the cable. Numerous difficulties were experienced with this apparatus, but these need not be detailed here; in consequence of the practical difficulties which arose it was not always possible to place complete reliance on the records obtained by its means. It was not possible when designing the instrument to foretell all its requirements, and probably considerable modifications could with advantage have been introduced. In place of a platinum thermometer it was possible to connect with the recorder a bolometer or Sunshine Receiver. This Sunshine Receiver was specially constructed to be capable of immersion in considerable depths of water, with the object of determining to what depth the effect of the sun's rays was directly felt, and also to detect, if possible, radiation from the loch.

It must be confessed that this elaborate and costly apparatus did not come up to our expectations, although by its means considerable light was thrown on several phenomena which would have otherwise been inexplicable. Great advantage was, however, taken of the *Rhoda*. Not only was it possible by means of this boat to observe in almost any kind of weather, but it was also possible to observe at all hours of the day or night; and during August 1904 a long series of observations was made by observing every two hours both day and night. In September 1904 several stations were established along the loch at which simultaneous observations were made three times a day, as it was then known that the original mode of arriving at the temperature distribution of the loch by cruises in a steam launch was open to grave criticism. These cruises unavoidably occupied the greater part of a day, and, in view of our results, it could not be maintained that the distribution of temperature shown by the observations even approximately represented the true state of affairs at any point of time, and it was found impossible to apply corrections to the observations which would make them comparable to observations made simultaneously at different points. Towards the end of September the work by members of the Lake Survey was discontinued, but it was enthusiastically taken over by members of the Order of St Benedict* at Fort

* In particular, the observations were in charge of the Rev. Fr. CYRIL VON DIECKHOFF and the Rev. Fr. ODO BLUNDELL.

Augustus, and they continued the observations till the end of April 1905, when the station was dismantled.

The detailed thermometrical survey was made, as already mentioned, from the *Rhoda*, and was only carried on down to a depth of 200 feet, primarily because of the difficulties in the way of observing regularly at greater depths; but it appeared, from observations made at other times, that the behaviour of the water at greater depths than 200 feet could always be explained by reference to the movements proceeding at lesser depths. One difficulty which threw doubt on the observations arose from the fact that the observation station was in close proximity to two of the largest rivers which enter the loch—the Oich and the Tarff. Very careful observations were made to determine how far the influence of these rivers made itself felt, and, with certain very interesting exceptions, which will be referred to afterwards,* it was found that the effect of these rivers was negligible at the *Rhoda*.

II. Yearly Changes.

The problem which confronts anyone who wishes to study the temperature of a loch is, broadly,—How does the loch gain or lose heat, and what phenomena present themselves during the cycles of changes which take place? What is the effect of wind and sunshine and other factors at different periods of the year? As a first step towards answering these questions I have prepared a table† showing the monthly means of temperatures at Fort Augustus, at different depths down to 200 feet, for the whole period during which observations were made. Where more than one series of observations had been taken in one day the first of these series alone was used in computing the mean temperature, so as to avoid giving too great weight to the observations of any particular day.

* See page 427.

† The mean Air Temperature in these tables is taken from the Registrar-General's Reports.

[Table.

Table I.

Monthly Means of Temperature at Fort Augustus.

Date.	July.		August.		September.		October.		November.		December.	
	1903.	1904.	1903.	1904.	1903.	1904.	1903.	1904.	1903.	1904.	1903.	1904.
Mean Air Temp.	54·9	56·8	54·0	55·6	52·6	53·5	46·4	47·7	42·1	40·3	35·7	39·2
Depth. Feet.												
0	54·7	51·4	53·4	56·3	52·0	53·5	49·6	49·3	46·5	46·8	44·1	43·7
50	51·0	49·9	50·7	53·1	51·4	53·0	49·2	48·9	46·5	46·7	44·0	43·7
100	49·1	48·1	49·4	50·1	50·8	51·5	49·2	48·4	46·4	46·6	44·0	43·6
150	47·6	45·7	47·4	47·4	49·2	47·7	48·3	47·3	46·2	46·3	44·0	43·6
200	45·7	44·5	45·9	45·3	46·7	45·0	46·3	45·6	45·6	45·6	44·0	43·6

Date.	January.		February.		March.		April.		May.		June.	
	1904.	1905.	1904.	1905.	1904.	1905.	1904.	1905.	1904.	1905.	1904.	1905.
Mean Air Temp.	39·0	40·5	36·6	38·1	38·8	41·0	44·7	42·2	47·9	49·5	54·1	56·0
Depth. Feet.												
0	42·7	42·6	41·9	41·8	41·5	41·5	41·5	42·2	43·6		48·5	
50	42·7	42·6	41·8	41·8	41·4	41·4	41·4	42·0	42·8		46·4	
100	42·6	42·6	41·7	41·7	41·3	41·3	41·3	41·9	42·6		45·4	
150	42·6	42·6	41·6	41·7	41·2	41·3	41·2	41·8	42·5		44·0	
200	42·5	42·5	41·5	41·7	41·1	41·2	41·1	41·8	42·3		43·1	

The values for the mean temperature in July 1903 are probably too high, as no observations are available for the first ten days of this month. Even without applying any corrections, there is great similarity between the means for the two years. This is especially noticeable from October to March; but for the other months also the similarity is very marked, and becomes obvious when the results are represented graphically (fig. 1). From this I have felt justified in assuming that these mean curves are typical of the curves for any one year in Loch Ness. I do not say that from them any quantitative idea of the quantity of heat in the loch can be arrived at; but I do think that these curves are typical of the temperature distribution throughout the loch. A month is a sufficiently long time over which to take an average, to eliminate any local peculiarities from the type of the curve. I should hesitate in a wide loch to draw any conclusions as to the temperature at the centre from observations made near one shore, as I attribute the distribution of temperature very largely to the influence of the wind, and the currents set up thereby, which are chiefly felt near the shores. But in a narrow loch such as Ness every point is sufficiently near one

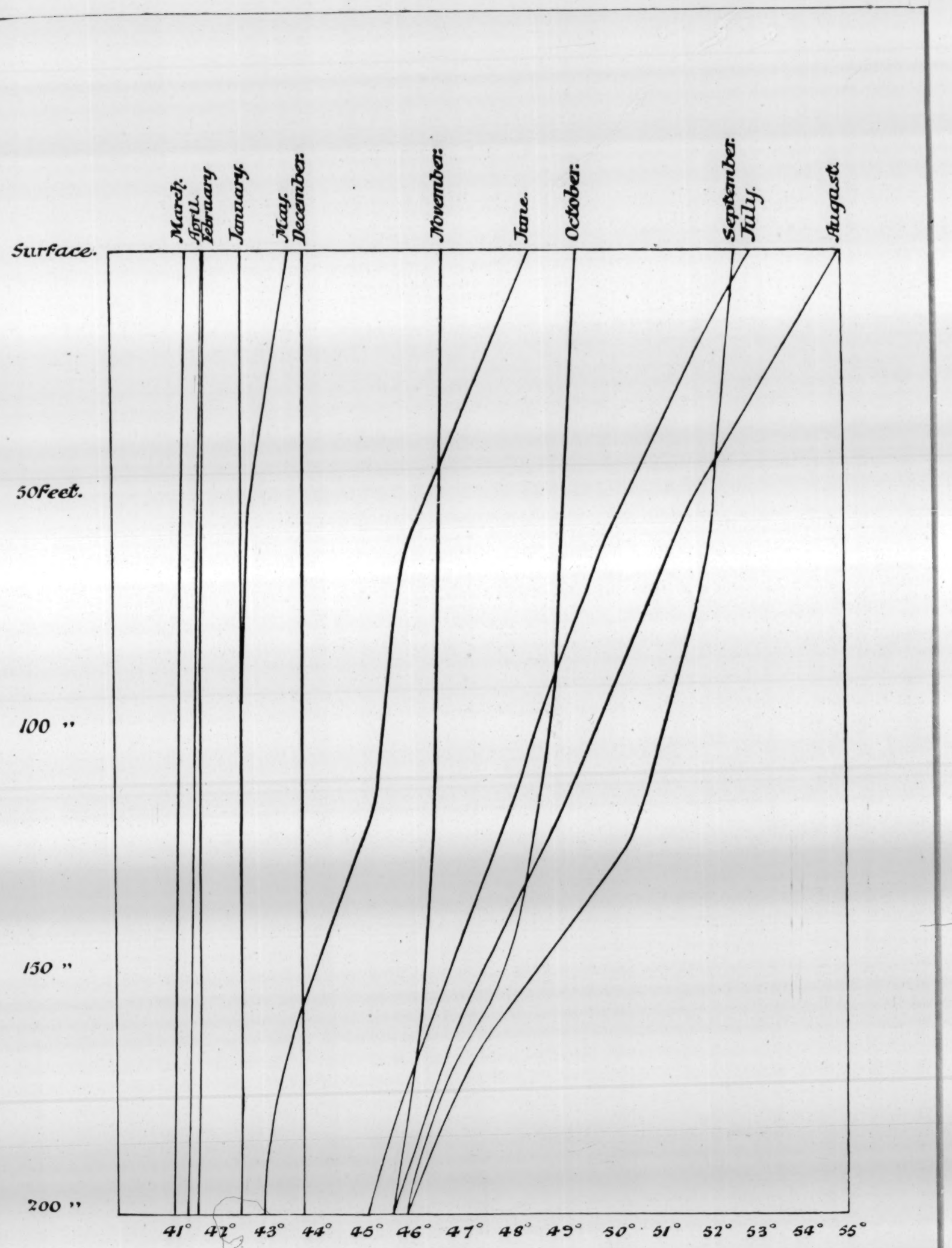
March.
April.
February
January.
May.
December.
November.
June.
October.
September.
July.
August.
Surface.
50 Feet.
100 "
150 "
200 "
41°
42°
43°
44°
45°
46°
47°
48°
49°
50°
51°
52°
53°
54°
55°

FIG. 1.

shore to be influenced in very much the same manner as water near the ends of the loch. No doubt the fact that there is a prevalent wind will make the typical curves for one end of the loch differ from those of the other end, but such a difference must be one of degree and not of kind. Fig. 1 shows the curves obtained by taking monthly means over the whole period of the observations. Fig. 2 shows on an arbitrary scale the quantity of heat in the loch throughout the year—this curve being obtained by assuming the curves in fig. 1 to be typical for the whole loch.

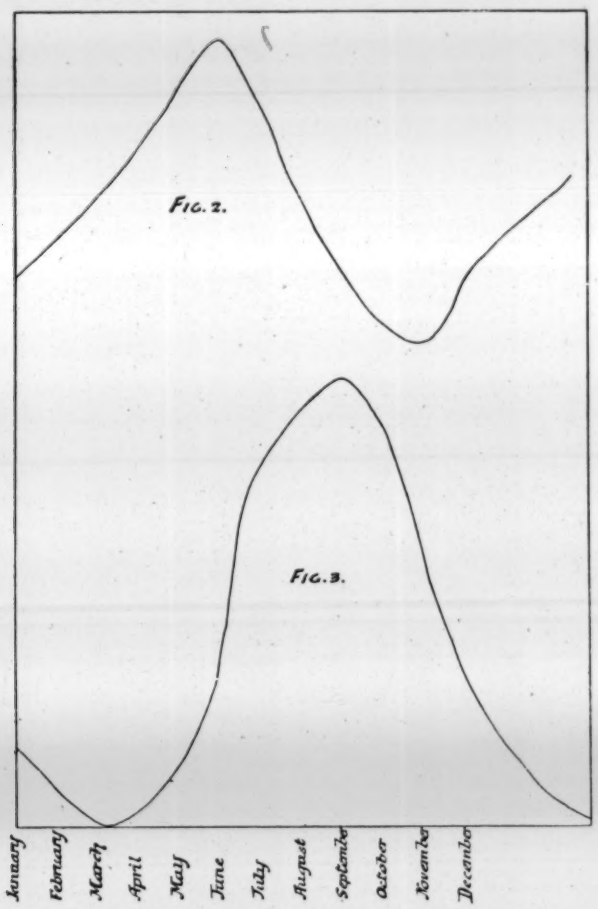

Fig. 3 shows the rate at which the curve in fig. 2 changes, and so represents the rate of change of temperature.

It thus appears that in September there is the greatest quantity of heat in the loch. Thereafter the loch cools rapidly until March or April, when the water begins to heat up again. It is perhaps worth while to notice that the mean air temperature at Fort Augustus in March for these two years is 39·9° F. and in April 43·4° F., and as the lowest temperature the loch reaches is intermediate to these, it is quite to be expected that the loch would first show an increase of temperature in March or April. And in other lochs the increase of temperature will be governed in the same way. When the average temperature of the air begins to be above the surface temperature of the loch, then the loch will begin to gain in heat.

The form of the typical curves is also instructive. From May till August we have an increase of temperature throughout the water at different depths, proportionate to the depth. This is true of the water above 200 feet. Below that depth the heating takes place more slowly, but even in the deepest water there is a range

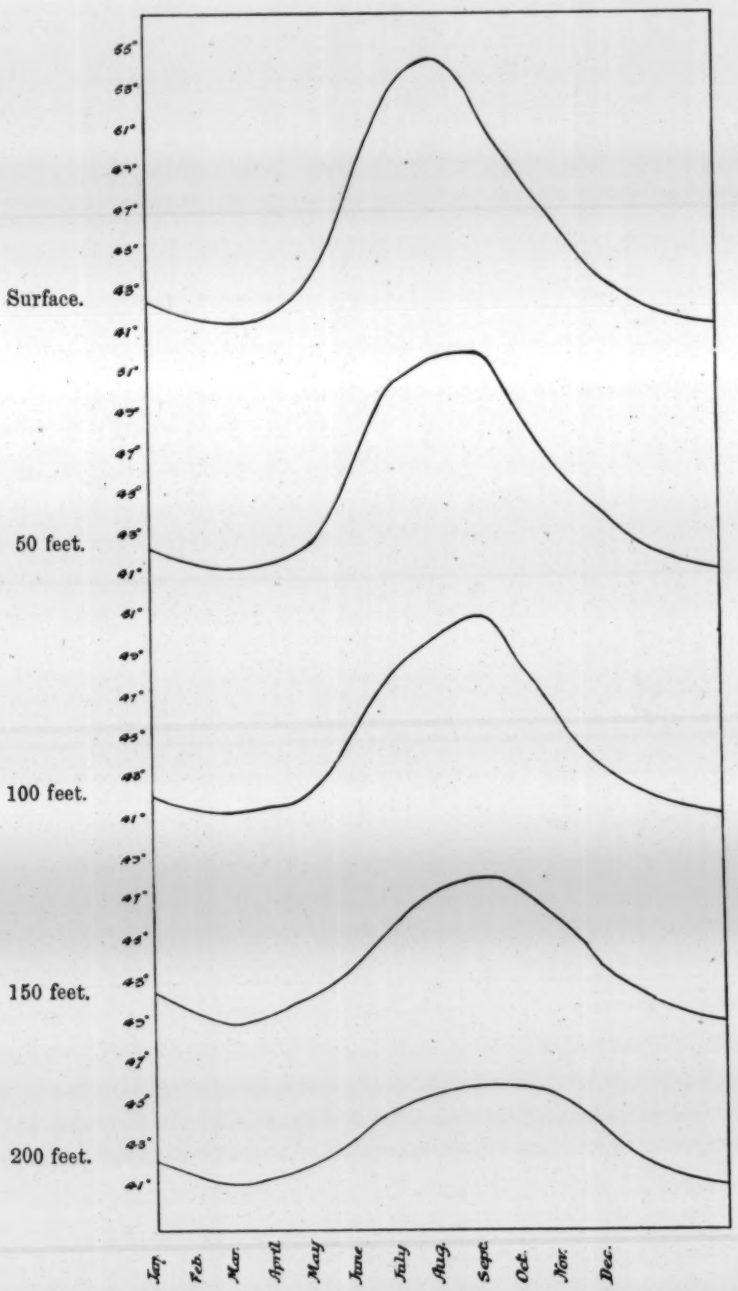

FIG. 4.

of temperature of about two degrees. The lowest recorded temperatures at the bottom of the loch are in April, and the highest in the middle of November. The mean air temperature of August for the two years is 54·8°, and of September 53·0°. The highest temperature of the surface layers is about 55°, though, of course, there are often higher temperatures recorded. Fifty-five degrees may be taken as the mean

surface temperature for August (approximately). One would then expect a change of type in the curve for September, as the air temperature has fallen considerably below the surface temperature, and in fact there is a remarkable change of type. The water cools off in an entirely different manner from that in which it gained in heat. It cools gradually from the top, and not uniformly through its whole bulk. This appears more clearly from fig. 4, which represents the mean temperature changes at the surface, 50, 100, 150, and 200 feet respectively, throughout the year. This diagram shows that whereas the surface layers begin to cool off in August, the lower layers go on getting warmer for another month or six weeks, and the loch is in fact gaining heat for a time after the surface begins to cool off. The highest temperature at 700 feet, as already mentioned, was recorded in the middle of November, or about three months after the loch began to show signs of losing heat, indicating that water at this depth is below the region of disturbance by wind and currents, and that the temperature changes are here the result of conduction.

It is difficult to form a definite opinion as to the cause of this change of type. There is nothing in the difference in the weather in spring and autumn which can explain this. The actual state of affairs in autumn is not very clearly shown by the typical curves. The curves in fig. 1 show clearly that there is, to a certain depth, water at a uniform temperature, and that thereafter the water gets gradually colder. Without referring at present to the cause of this, it may be stated that in reality there is a layer of water at uniform temperature of gradually increasing thickness. Where this layer ends there is an abrupt change of temperature, and below this point, which is called the *Sprungschicht*, the water gradually decreases in temperature. The *Sprungschicht*, however, oscillates up and down, so that when the mean temperature is taken over a considerable period, the effect of this oscillation is to take away from the typical curves all indication of a sudden and abrupt change of temperature.

III. Influence of Wind. *Sprungschicht.*

The appearance of the *Sprungschicht* is, to my mind, due to the effect of the wind. The general effect of wind on a fresh-water loch is now well known.* The water on the surface is blown along by the wind and accumulates at the windward end of the loch. The place of the water so transferred to the windward end has to be filled. Consequently a "return current" is set up and water from the deeper parts of the loch rises to the surface. Thus there is always a process of circulation while there is wind blowing. In a loch like Ness, where the water never falls below the maximum density point, it is always warm water which is blown along the surface and relatively colder water which rises to take its place, with the result that there is always a greater quantity of warm water at the windward than at the lee end of the loch. Fig. 5 shows an

* In particular, see Sir John Murray's paper "On the Effects of Winds on the Distribution of Temperature in the Sea- and Fresh-water Lochs of the West of Scotland," *Scottish Geographical Magazine*, July 1888.

ordinary distribution of the isotherms in early spring. This diagram is from observations made by Sir JOHN MURRAY in April 1887.* It shows that the isotherms are very nearly vertical, and it was always found that, when the differences of temperature throughout the loch were not great, the slopes of the isotherms were much greater than when the differences of temperature were considerable. All efforts to trace the return current directly and quantitatively have failed, though indirect indications of it are not infrequent. In spring it should not be so well marked as in autumn, as in spring there are no great differences of temperature and no well-marked condition of stratification. The fact that the heating takes place so uniformly down to, say, a depth of 250 feet, can, I think, only be explained on the assumption that in spring the influence of the return current is felt to at least this depth. In autumn, however, it is the water which is being cooled off which is blown along the surface, and also, at that time of year the loch is in a well-marked stratified condition. The water which is blown along by the wind will

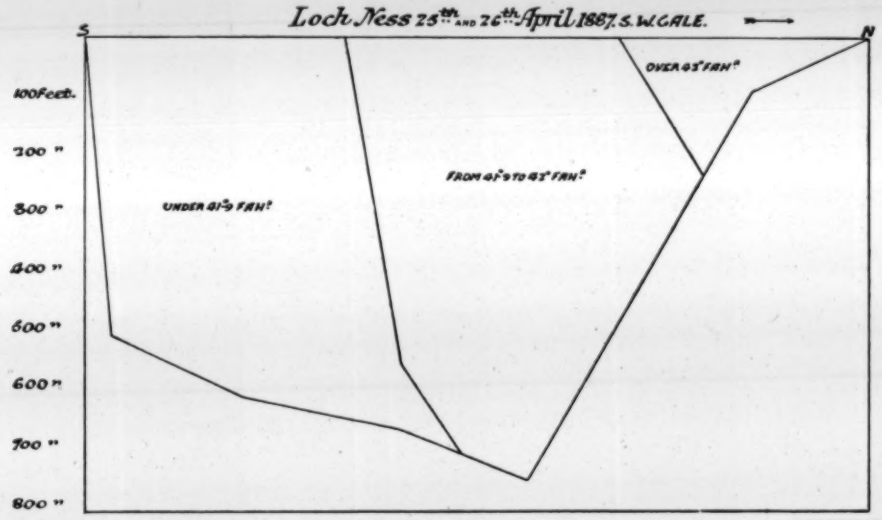

FIG. 5.

accordingly have a tendency to sink. We know that at this time of year there is a layer of water at the surface of nearly uniform temperature, which is originally due to the mixing action of the wind in producing waves, and the action of the wind in blowing water along the loch will have the further effect of increasing the depth of this layer. There will also be a tendency towards the formation of this layer when at any time the temperature of the air is lower than that of the water, so that even in midsummer during the cool evenings and nights this influence is at work; and this will account for the early appearance of the *Sprungschicht*. As the *Sprungschicht* becomes more marked the effect of the wind is almost entirely confined to this layer of approximately uniform temperature, and the return current takes place mainly along the surface of separation between the cold and warm layers. It is not easy to say how far the influence of the return current is felt, but it would appear that it is not felt at any great distance from the ends of the loch. Former deductions have been based on

* *Scottish Geographical Magazine*, July 1888.

observations extending over the greater part of a day, and this has made it difficult to examine the operation of currents. Fig. 6 shows graphically two series of observations made within eight hours of one another. These show entirely different types of curves, and from such curves as these it is quite impossible to form any idea either of the temperature distribution of the loch or of the currents which are at work to

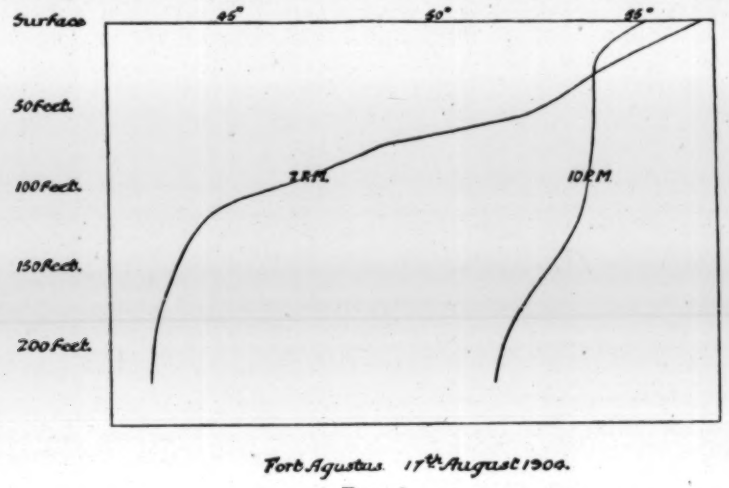

FIG. 6.

effect such changes. This will serve to illustrate how great is the need for simultaneous observations. In this direction there is still great room for work in observing lake-temperatures. In September 1904, for a short time simultaneous observations were made. If we can judge from these somewhat meagre observations, the first effect of

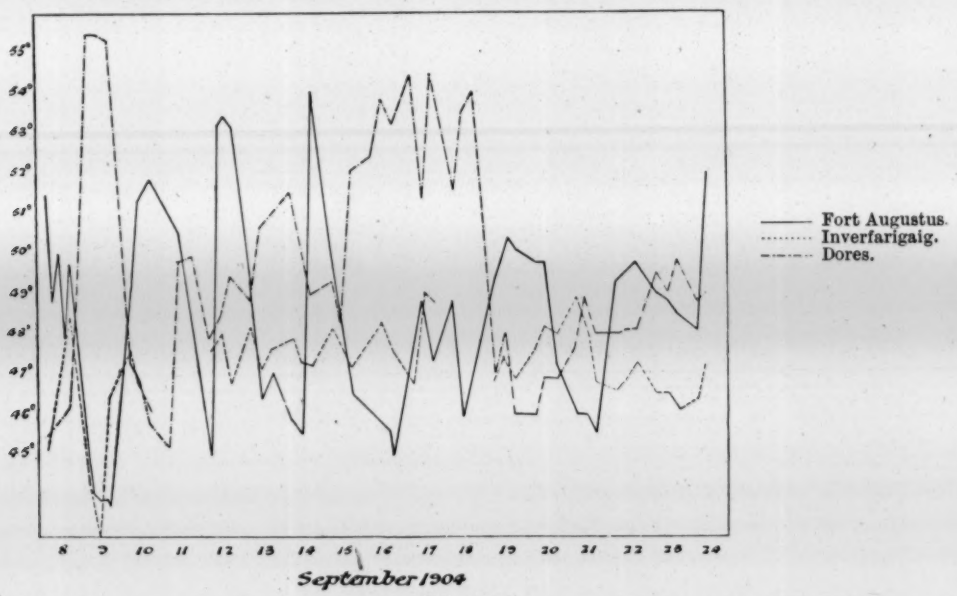

FIG. 7.

a change of wind is to straighten out any sinuosities which appear on the isotherms. The general condition of the isotherms in settled weather when represented graphically reminds one of a fan. They radiate out from the windward end of the loch. When the wind changes direction, this fan arrangement gradually changes with the wind. Fig. 7 represents the observations made at 150 feet at this time at Fort Augustus,

at Dores, which is at the N.E. end of the loch, and at Inverfarigaig, which is near the centre of the loch. About 16th September the wind changed from N.E. to S.W. This was followed by an increase in temperature at 100 feet, and by a relatively much greater change at 150 feet. This I attribute to the fact that the return current takes place along the surface of separation at the *Sprungschicht*, gradually losing itself among the surrounding layers. At this time of year the *Sprungschicht* is nearly at 150 feet, which explains why the increase should be relatively so much greater at that depth than at 100 feet. There is hardly any appreciable increase in temperature at 200 feet. At Inverfarigaig there is nothing in the curves which would lead one to expect that there had been a change of wind. At Fort Augustus the change affects practically only the surface layers above the *Sprungschicht*, and these layers fall greatly in temperature. This is probably because the water which has been blown along the surface is replaced by cold water rising from the neighbourhood of the *Sprungschicht*. At Invermoriston, five miles from Fort Augustus, there seemed also to be a corresponding fall in temperature through the first 100 feet, as though the influence of the return current was felt thus far. Thereafter it would seem to lose itself entirely, and indeed it is not possible to assert that it is felt to this distance. Mr Watson * states that the amount of water at any given temperature is nearly constant during all the changes which occur, and he arrived at this conclusion by measuring the areas between isotherms drawn in a diagram such as is shown in fig. 6. I think that Mr Watson's observations were not sufficiently complete to warrant this statement, and I can only say that with the more detailed observations at my disposal I have not been able to verify this statement. He is also of the opinion that in stormy weather the loch loses heat much more rapidly than in calm weather, and as to this also I have not been able to satisfy myself.

The next step in the temperature changes which occur is that the *Sprungschicht* gradually descends. Above the *Sprungschicht* there is always the layer of water at nearly uniform temperature, but the temperature of this layer is always decreasing. Below the *Sprungschicht* there is a gradually decreasing layer of water the temperature of which is gradually increasing both by convection and by conduction. So the *Sprungschicht* gradually sinks until finally it reaches the bottom of the loch, and at last the loch is of practically uniform temperature throughout.

IV. Quantity of Heat in the Loch.

The yearly cycle of changes is of course very largely dependent on the meteorological conditions of the year. A cold spring will mean that the time at which the loch begins to gain heat will be delayed. A warm spring will mean that the water will heat up rapidly, as it is in spring that the water is coldest. In a very warm spring we may expect that the bottom temperatures will be considerably higher in the year which follows than if the heating had taken place gradually. Also extremes of cold will have

* *Geographical Journal*, October 1904.

most effect when the water is warm. If in early autumn there is a cold spell of weather with little sunshine, the quantity of heat in the loch in the succeeding winter may be much less than in another year with a much colder winter. The point to which the loch is cooled down will of course vary slightly from year to year.*

In early spring, the temperature is very nearly the same throughout the loch, and the temperature at this time will approximately determine the abysmal temperatures in the succeeding year, but even the lowest layers of Loch Ness have a range of about two degrees in any one year. I have made a rough calculation of the amount of heat which enters the loch during the year, by assuming that in the coldest time of year the loch has a uniform temperature of 41·2° F., and arriving at the maximum amount of heat in the loch from the detailed temperature observations made in September 1904. This calculation gives the quantity of heat which enters the loch as approximately $1{\cdot}9 \times 10^{16}$ gram calories for the whole loch. Dr Knott† states that the total quantity of heat supplied is about $7{\cdot}2 \times 10^{16}$ gram calories, or about four times the amount of heat which according to the above calculation actually enters the loch; and this seems a very reasonable proportion for the amount of heat supplied to bear to the amount of heat stored up in the loch.

V. Temperature Seiche.

I have in a cursory manner discussed the temperature changes which take place throughout the year. I now wish to direct attention to some of the phenomena which accompany these changes. The most important of these which calls for consideration is what I may call the temperature seiche. The existence of a temperature seiche was not suspected when the observations were begun at Fort Augustus. It very soon became apparent, however, from the numerous observations which were made that movements of great magnitude were in progress, and for a long time the reason of these changes was sought in vain. At first it was tried to explain the changes by simple currents and then by the influence of rivers, but it was impossible to get a workable theory based on any such considerations. Gradually it came to be recognised that the changes were consequent on the unstable conditions set up by the action of the wind in piling up warm water at one end of the loch, and the observers were able with some degree of accuracy to predict the changes which would follow a storm or a change of wind; but it was some time before the periodic nature of these changes was fully understood. Mr E. R. Watson, in a paper published in the *Geographical Journal* for October 1904, his results having been previously communicated to this Society, sought to give an explanation of the observations, and though many limnologists have expressed themselves sceptical of the soundness of his deductions, no other explanation has been put forward which can seriously be called an explanation. Put briefly, the theory is this. In autumn, when the *Sprungschicht* is in

* The waters of Loch Ness have never been known to freeze save round the shores, as the water is never cooled down to the maximum density point.

† *Proc. Roy. Soc. Edin.*, 1900–1, vol. xxiii. p. 296.

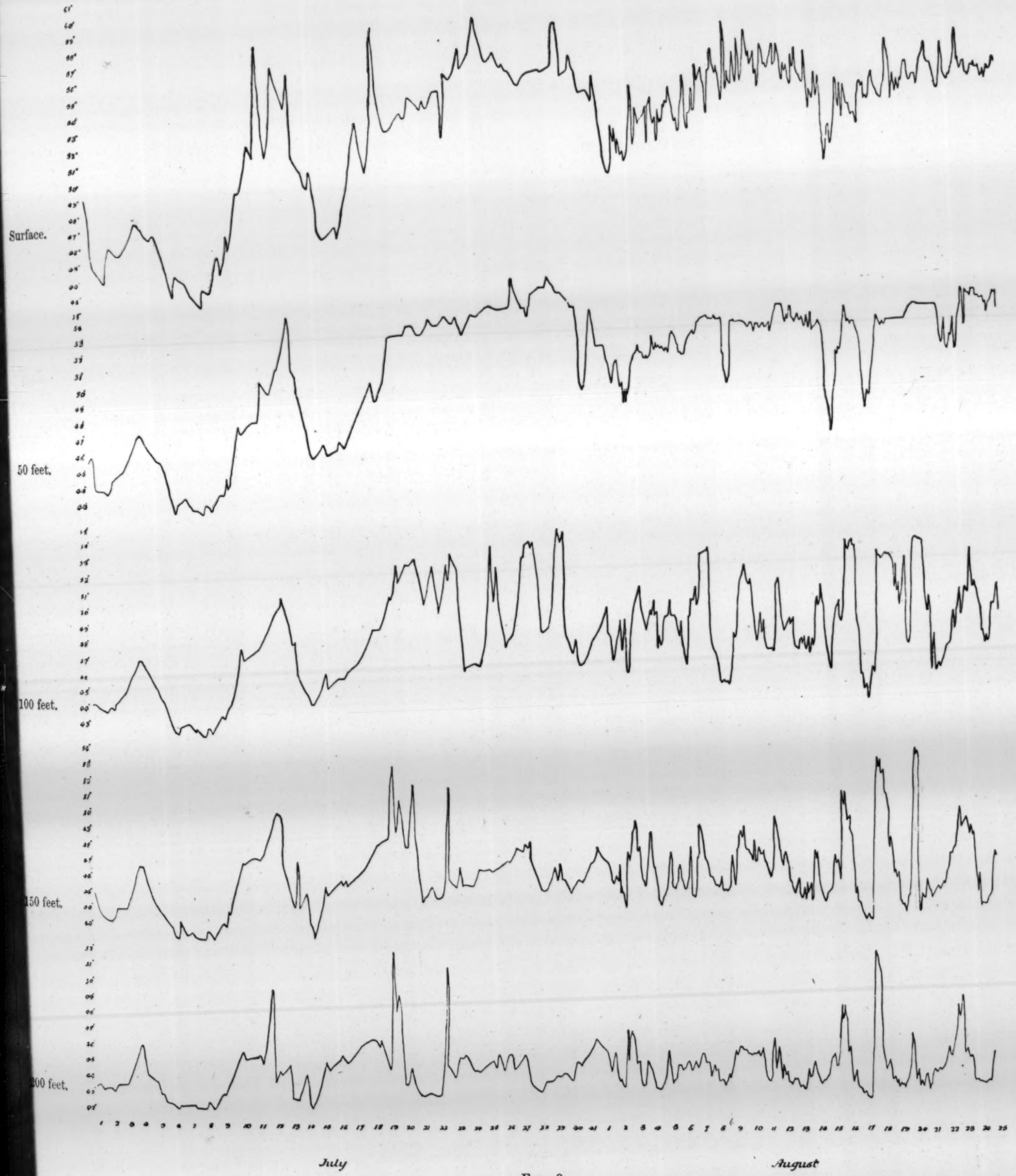

FIG. 8.

evidence, the water is in a well-marked stratified condition, and there is a more or less well-marked surface of separation between the upper layer of warm water and the lower layer of cold water. There is an arrangement similar, say, to a layer of oil resting on a layer of water. In this condition it is possible to have an oscillatory movement in the lower layer independent of movements progressing in the upper layer. The possibility of such oscillations may be readily verified experimentally, and rough calculations of what should be the period of such an oscillation in a loch support this theory.

The observations for 1903 have been sufficiently dealt with by Mr Watson. In 1904, during a considerable part of the month of August, observations were made every two hours, day and night. The observations made in July and August are shown graphically in fig. 8. The number of the observations in August tends to make the curve obscure owing to the embroideries, but beginning on 23rd July there is a pretty well-marked oscillation at 100 feet, and even earlier there are evidences of a periodical movement. The long period changes prior to that are attributable to wind. For instance, on 11th and 12th July there was a strong N.E. wind which brought all the warm water to the Fort Augustus end of the loch, and from the 18th onwards there were N.E. winds, which again show their effects at 200 feet. The evidence of the influence of the wind at these depths is in accordance with what has already been said about the warm water blown to one end of a loch being quickly spread through the whole body of water if the *Sprungschicht* has not made its appearance. The change of wind on 30th July gave rise to an unstable condition of the isotherms (the normal direction for the isotherms is of course horizontal). In this case the result of this unstable condition was the beginning of a temperature seiche. Thereafter, as the *Sprungschicht* becomes more well marked, the changes in the lower layers go on independently of the changes in the upper layers, which are caused directly by the action of wind, sunshine, etc. Sudden changes of temperature such as are shown on 8th and 14th August at 50 feet are easily explained on this theory. The temperature seiche for practical purposes may be looked on as an oscillation of the *Sprungschicht*. When the *Sprungschicht* passes any particular point in the loch there will be a rapid change of temperature at that point, for above the *Sprungschicht* there is warm water, and below, the water is comparatively cold. In no other way, so far as I am aware, can these rapid changes be explained, and to my mind they form one of the strongest supports of this theory. Fig. 9 shows a record obtained by means of the electrical recorder on 17th August with a thermometer at 100 feet. It shows that in a quarter of an hour there was a rise in temperature at 100 feet of 8·3°, and though such sudden changes were by no means usual they are not unparalleled. On the same date at 150 feet the temperature observed by means of mercury thermometers rose from 43·6° to 53·5°, or practically 10°, between 2 p.m. and 4 p.m. The distinctness of the surface of separation will determine the rapidity with which these changes take place.

It was thought that these curves were not definitely conclusive of the periodic nature of these changes. The curves were certainly confused at some points. This could hardly be otherwise, considering the complexity of the forces at work—wind,

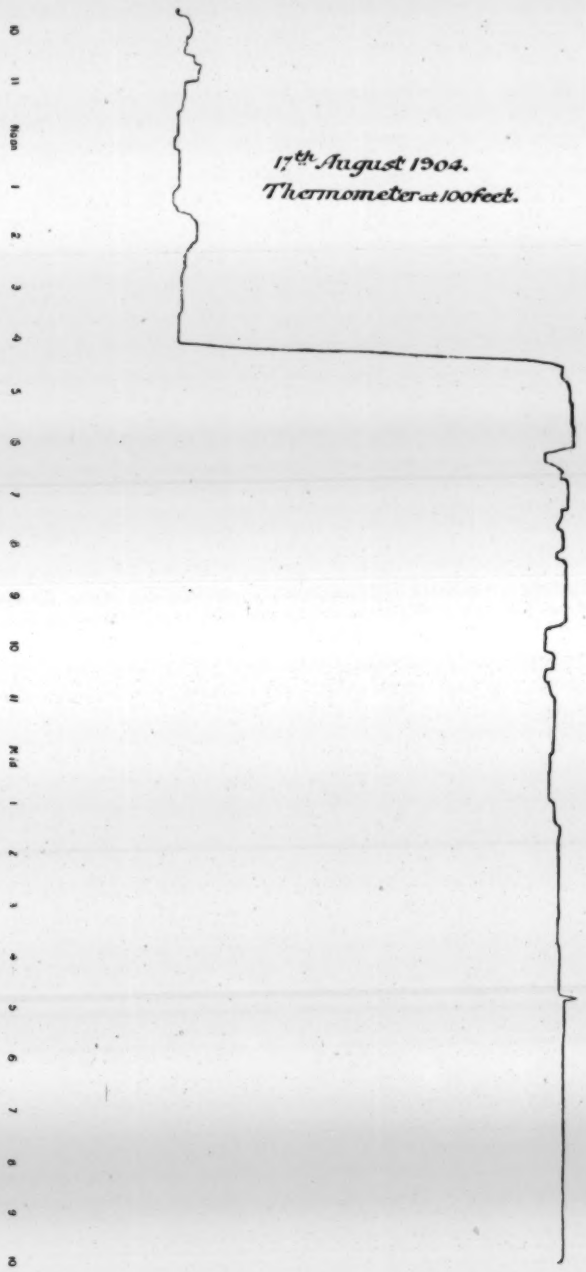

FIG. 9.*

currents, etc.; and to those accustomed to work with seiche records obtained from limnographs they cannot appear more confused than the records which are often thereby obtained. For with ordinary seiches there is always interference between seiches of different nodality, and there is no reason to doubt that there should be like interference in the case of temperature seiches. It was hoped definitely to settle

* The actual scale of the platinum thermometers was, for practical reasons, not accurately determined. The sudden change between 4 p.m. and 5 p.m. means an increase in temperature of about 9° F.

the question by the observations which were taken in September 1904, the results of which are represented in fig. 7, which has already been explained. The opposition between the curves for Fort Augustus and Dores is as good as could have been hoped for. Most unfortunately, from this point of view the temperature seiche which was in progress when the observations were commenced was disturbed by the wind changing from N.E. to S.W. about the 16th, and so all the warm water was carried towards Dores. The effect of a change of wind (it may be of degree) is to disturb any existing seiche. This is due, no doubt, to the damping effect of the currents set up by the wind, and also to the change in the distribution of the water, which means a difference in the period of the seiche and also a displacement of the node.

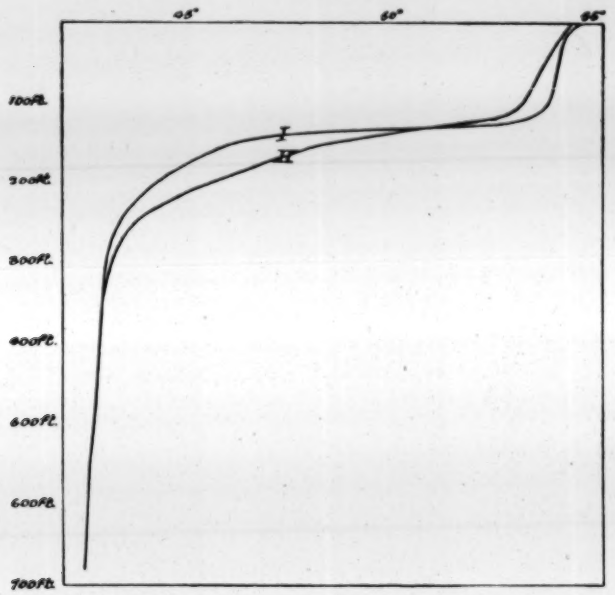

FIG. 10.*

This explains the sudden and continuous rise in temperature shown in the Dores curve. The Inverfarigaig curve shows much less disturbance than either of the other two curves, and this points to the presence of a node somewhere in its vicinity. Most of the disturbance which is shown on the Inverfarigaig curve would seem to be due to a binodal seiche of approximately half the period of the fundamental seiche, which, from these curves, appears to be about two days. A rough calculation of the period agrees very closely with this observed value. The mean depth of the loch may be taken as 450 feet. Fig. 10 shows two temperature-depth curves for this time of year, from which it appears that the depth of the surface layer may be taken as 150 feet. This leaves for the mean depth of the cold layer say 300 feet. The mean temperatures of the layers for the purpose of this calculation may be taken as 54° and 43° respectively. Employing the formula

$$t = \frac{2l}{\sqrt{\frac{g(\rho - \rho')}{\frac{\rho}{h} + \frac{\rho'}{h'}}}}$$

* I, Invermorriston, noon, 13th September 1904 ; II, Inverfarigaig, noon, 17th September 1904.

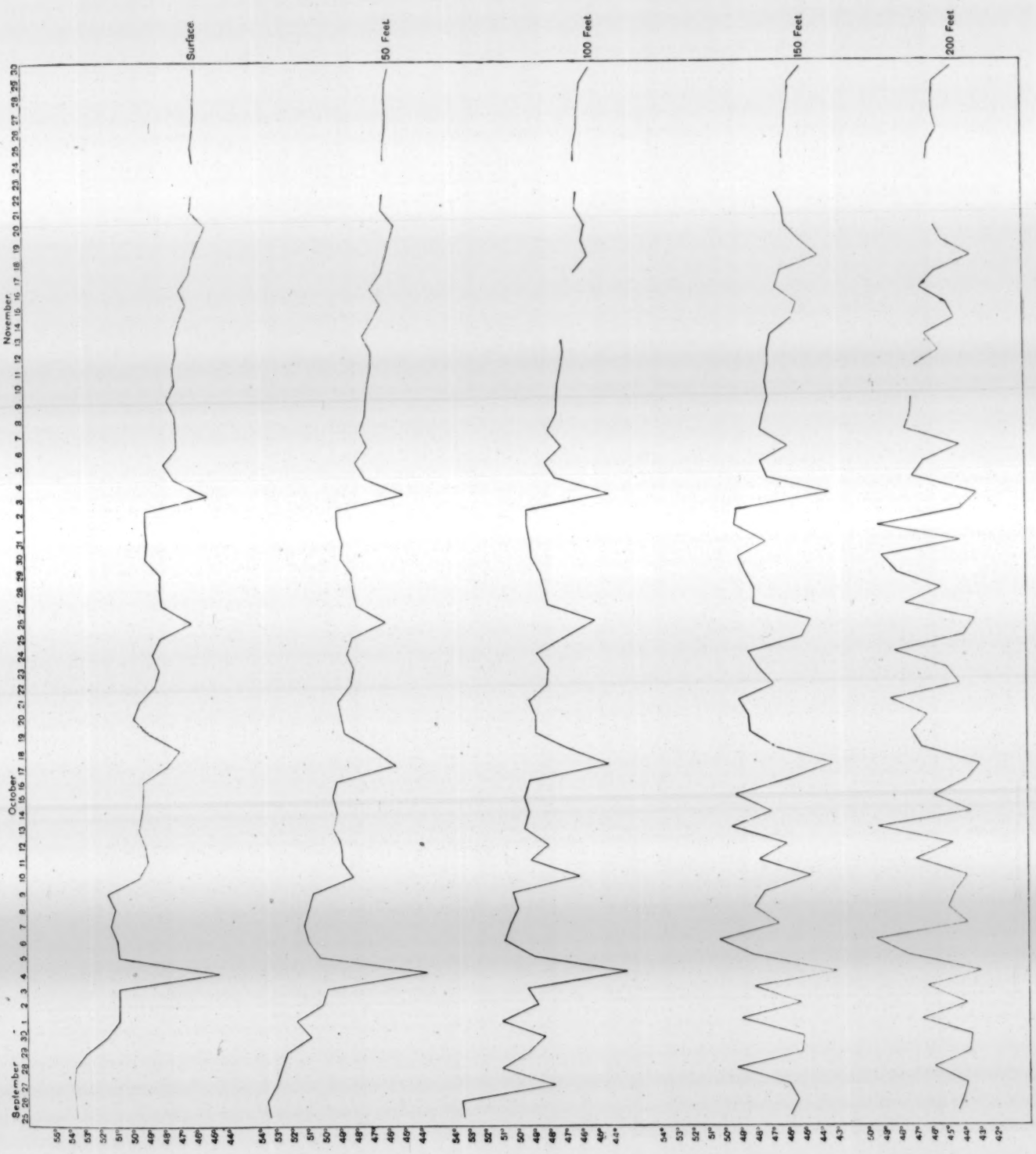
Surface
50 Feet
100 Feet
150 Feet
200 Feet
September
October
November

Fig. 11.

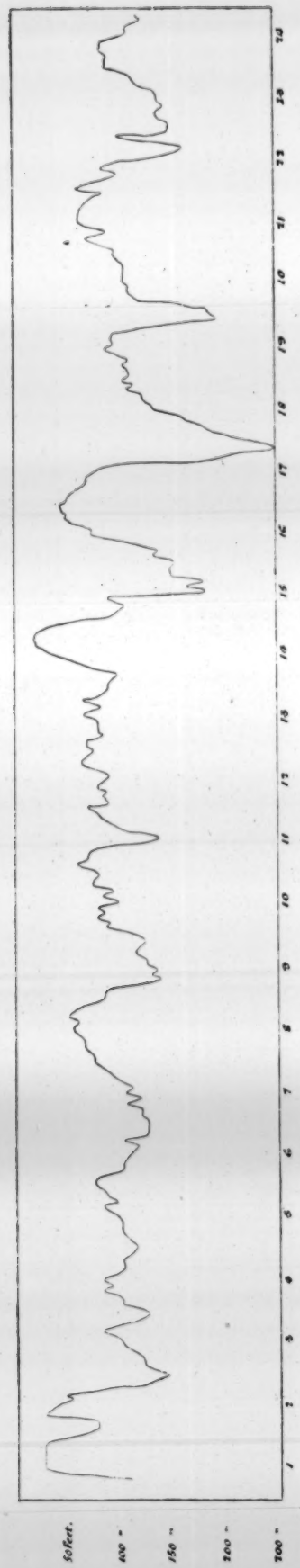

FIG. 12.

where l is the length of the loch, g the acceleration due to gravity ρ, ρ', h and h' respectively the densities and depths of the cold and warm layers, the period of the temperature seiche works out at two days six hours, which is certainly a far closer approximation to the observed period than could have been anticipated considering the rough data employed. The period is not constant during the year. Indeed it changes very considerably. Take the case where the *Sprungschicht* has sunk to a depth of 200 feet and where the temperature of the upper and lower layers is respectively 49° and 43°. The period then works out at three days ten hours. Such a distribution is typical of late autumn. Fig. 11, which is prepared from a diagram drawn by Father CYRIL VON DIECKHOFF, shows graphically observations made in late autumn, and it also shows very clearly the continuance of the seiche and the lengthening of the period as the year progresses. It also shows how the *Sprungschicht* gradually sinks until by the end of November the temperature seiche has practically ceased to affect the first 200 feet of water. Changes at this depth can then be traced directly to other causes.

These diagrams do not represent the temperature seiche in the same manner as the curves drawn by a limnograph represent the ordinary seiche. The diagrams show the variations of temperature with time at certain depths. To make a diagram more comparable to the ordinary seiche record it is necessary to show the variations that take place with time in the depth at which water at a definite temperature is obtained. Fig. 12 shows the depth at which there is a temperature of 50° at Fort Augustus during the month of August, and so it is strictly comparable to the ordinary limnogram. This diagram shows that the temperature seiche has the remarkable amplitude of 200 feet at times, and that 100 feet is quite an ordinary amplitude. The very flat top which the curve has on 1st August is, I think, instructive. I believe it to be due to the influence of the sun being directly felt at the depth of 25 feet, at which depth there is then a temperature of 50°. There is a tendency for the curves to have flat tops

all through, and this may be due to a similar reason, but it is worth while to notice here that many of the limnograms for Loch Ness also show curves with flat tops, and the reason may perhaps more correctly be sought in the shape of the basin of the loch. It is quite possible that when the lower layer of the loch acts so independently the upper layer should also act independently, and from this point of view I have examined limnograms for the time of year when the *Sprungschicht* is best marked. In some of the records there seemed to be a trace of a seiche in the upper layer alone. In no case, however, was the evidence sufficiently clear to warrant a definite assertion.

VI. Floods.

Reference has already been made to the influence of rivers on the observations made at Fort Augustus, and I now wish to refer to the effect produced by heavy floods, and as an example I shall take the floods which occurred in the middle of October 1903.

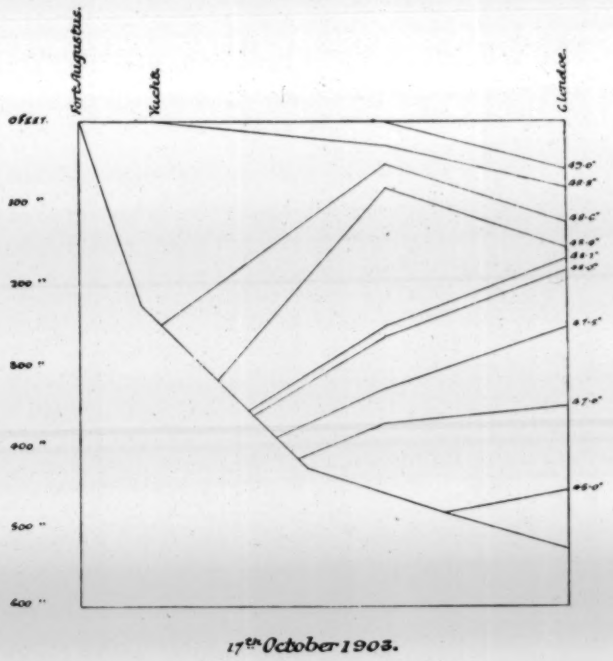

Fig. 13.

There was very heavy rain on the evening of the 15th, which continued till the evening of the 16th. Both the rivers, the Oich and the Tarff, came down in flood. The first effect noticeable was a great lowering of temperature at Fort Augustus, owing to the water brought down by the rivers being colder than the mean temperature of the loch. An effort was made to determine whether the temperature distribution at Fort Augustus was typical of the whole loch, and for this purpose numerous thermometrical soundings were made in the neighbourhood of Fort Augustus, with very interesting results, shown in fig. 13. It appears from this diagram that the distribution at Fort Augustus is very local, and that at a distance of about one mile the effect of the floods is not great. One very interesting point is that the water brought down by the rivers seems to keep

very much together. For instance, the temperature of the water brought down by the Oich was 48·3°, and accordingly there is a considerable quantity of water between the isotherms for 48·2° and 48·4°. Again, the temperature of the water brought down by the Tarff was 48·7°, and there is also a considerable volume of water between the isotherms for 48·8° and 48·6°. We may expect, then, in general that the water brought down by rivers will not have any great effect on the water as a whole at its mouth, but, if we look upon the isotherms as membranes, that it will intrude itself between isotherms for temperatures slightly higher and slightly lower than that of the river water. In summer the temperature of the rivers is as a rule higher than the surface temperature of the loch, and so river water will merely lie on the surface. Thus it will not disturb the temperature changes at any great depth. In winter, on the other hand, the temperature of the rivers is as a rule colder than the temperature of the surface water. The water which is brought down will as a consequence sink to the bottom of the loch, and this will tend to make the water at this end of the loch of lower temperature than at any other part of the loch.

VII. Surface Temperatures.

There still remain for consideration the temperature changes which occur above the *Sprungschicht* and near the surface. It was at first hoped that by means of the sunshine receiver some information could be obtained as to radiation into or from the loch. With the weather conditions which obtained during the time observations were made it was impossible to obtain any reliable information in this respect. The mechanism of heating and cooling could not be closely followed. So large a sheet of water was never at rest or free from currents.

There is no trace of radiation from the loch in any of the records obtained, even on the most likely occasions, so that any information which can be gathered from the observations is of a purely negative character. As to the depth to which the direct effect of the sun's rays is appreciable, there are slight indications in winter that the recorder was sensitive to the sun's rays at a depth of from 12 to 16 feet, but this is really mere conjecture. In August, with the sunshine receiver at a depth of 10 feet there was quite an appreciable indication on the records of the difference between night and day, but the deflection of the galvanometer of the recorder was so slight that the difference between brilliant sunshine and cloud could not be detected. With the sunshine receiver in air the deflection was nearly 150 times as great as with the receiver at a depth of 10 feet. After a depth of about two feet it was not possible to distinguish between sunshine and cloud.

Some interesting records of surface temperatures were obtained by means of the platinum thermometers. The surface temperature is seldom in a steady state save occasionally in late autumn or winter, when there is a considerable body of water of uniform temperature near the surface, and when at the same time the temperature of

the air is not greatly different from that of the water. During frosty weather the curves obtained were of a much more ragged nature than were the curves obtained in more temperate weather. This is probably owing to convection currents. Towards the end of September inverse stratification was noticed on one or two occasions, and this gives an explanation of the raggedness of the curves representing the temperature at the surface at this time. The surface water first cools down and then gets slightly heated up by mixing with the warmer layers below it.

Towards the end of May 1904, for three consecutive days the platinum thermometer was kept near the surface, and on each of these days the surface temperature varied more or less gradually. But in each case, in the evening, between 8 and 10 o'clock p.m., there was an abrupt change of temperature, followed by numerous rapid changes of temperature. On all three occasions the abrupt change was preceded by a rise in temperature of the upper layer water. The records for these three days are shown in fig. 14. The probable reason of these changes is, I think, to be sought from the fact that the surface temperature will have fallen considerably owing to the cold evenings, and so the water will have got into an unstable condition. Convection currents would then be set up, which would account for the rapid changes shown in the embroideries on the curves. The facts that the first sign of the changes which occur is a rise in temperature of the upper layers can only mean that the mean temperature of the water above 5 feet (the depth to which observations extended) is greater than the temperature of water at 5 feet, and that consequently when there is a tendency towards equalising the temperature of water to this depth, the water at 5 feet must rise in temperature. Later in the year, when the evenings are not so cold, and when accordingly the water does not cool off so rapidly, there are still indications of a like change, but at a much later hour, which is in agreement with the explanation which I have suggested. These convection currents, if they are such, do not reach to a greater depth than 10 feet, or at least there is no evidence of their doing so. The records of temperature at 10 feet at this time of year are rather scanty, but from the records which there are it would appear that it is only in the first 5 feet or so that these rapid changes at the surface are of any considerable amplitude.

Towards the end of May the records of temperature at the surface began to show rapid changes of great amplitude. So erratic did the curves obtained by means of the Callendar recorder appear that they were at first attributed to instrumental errors. But the changes were checked by means of mercury thermometers. It was not possible, either, to attribute the changes to wind, for they occurred on the calmest days. Nor can they have been due to river influences, for they were also observed at Dores, where there is no river entering the loch to make the observations suspicious. On one occasion, in two minutes the surface temperature was found to change as much as 6° F. It is difficult to find any adequate explanation of this. On another occasion, when there was a quantity of pollen from flowers on the shore suspended in the loch, it was observed from the motion of the particles that different layers of water were moving in

different directions, and the surface waters were evidently in a very agitated condition, although the surface of the water was quite calm. Everything goes to show that heat is communicated from one part of the loch to another by convection more than in any other way (leaving out of consideration the effects of winds, which have already been discussed). Another fact which strengthens this view is that there are frequently lesser *Sprungschichts* at different depths, and in the neighbourhood of all these there

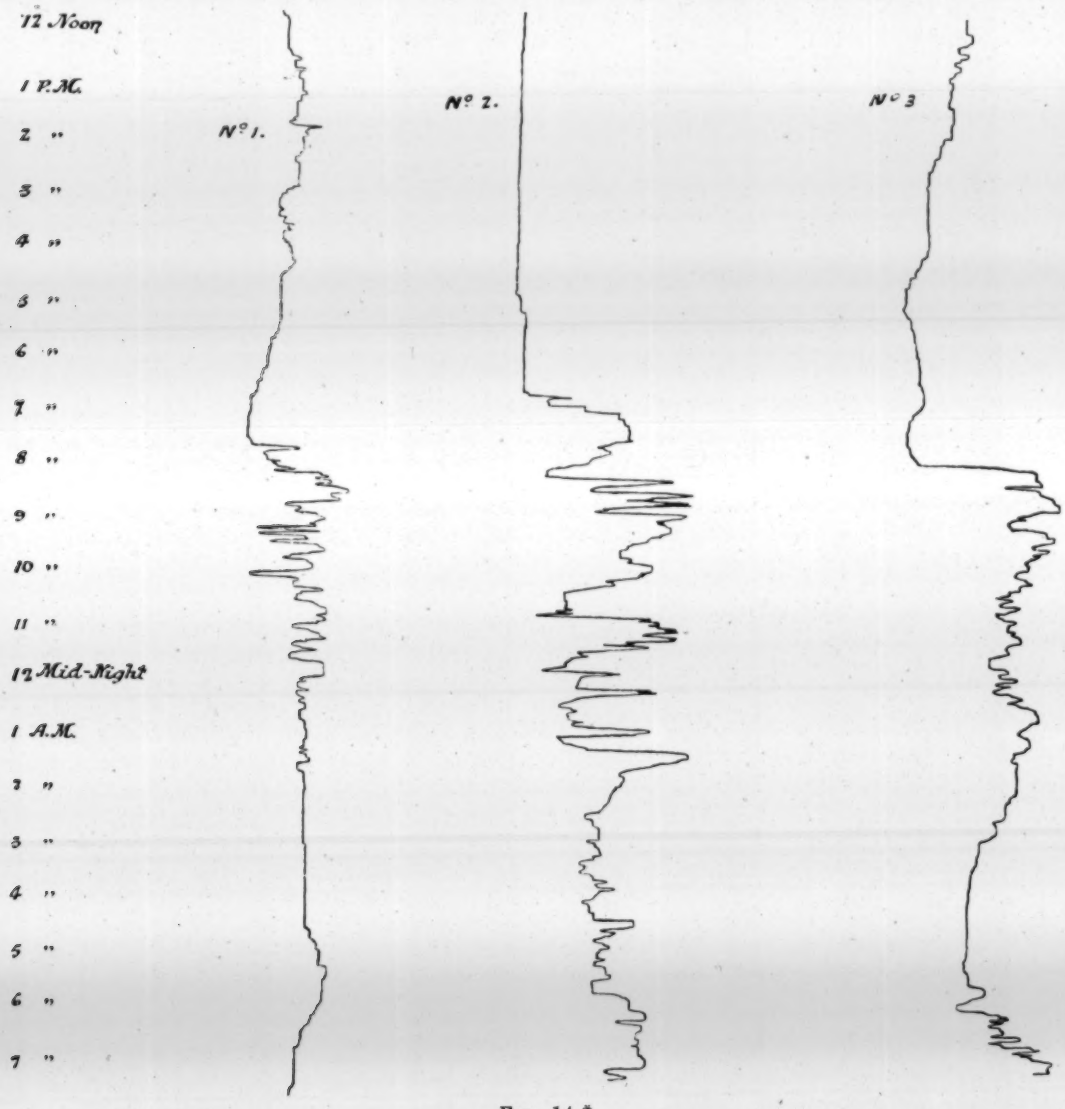

FIG. 14.*

must be convection currents set up. The behaviour of water in the neighbourhood of a *Sprungschicht* is very similar to the behaviour of water near the surface. Before this was understood, the observers were often puzzled when working with mercury thermometers by obtaining readings which seemed to show the presence of very marked inverse stratification, which always disappeared in a very illusory fashion when any attempt was made to follow it up. An explanation was offered by the platinum thermometers. The curves obtained by means of the recorder with the thermometer at various depths

* No. 1. Thermometer at 5 feet, 22–23 May 1904. No. 2. Thermometer at 5 feet, 23–24 May, No. 3. Thermometer at surface, 24–25 May. See also footnote, page 423.

were seldom very smooth—frequently, no doubt, there were instrumental variations. But often the changes were demonstrably not instrumental. Fig. 15 is typical of a great many curves. It is the record obtained with a thermometer at 100 feet on 18th and 19th August 1904. It shows very clearly the changes which were in progress at that

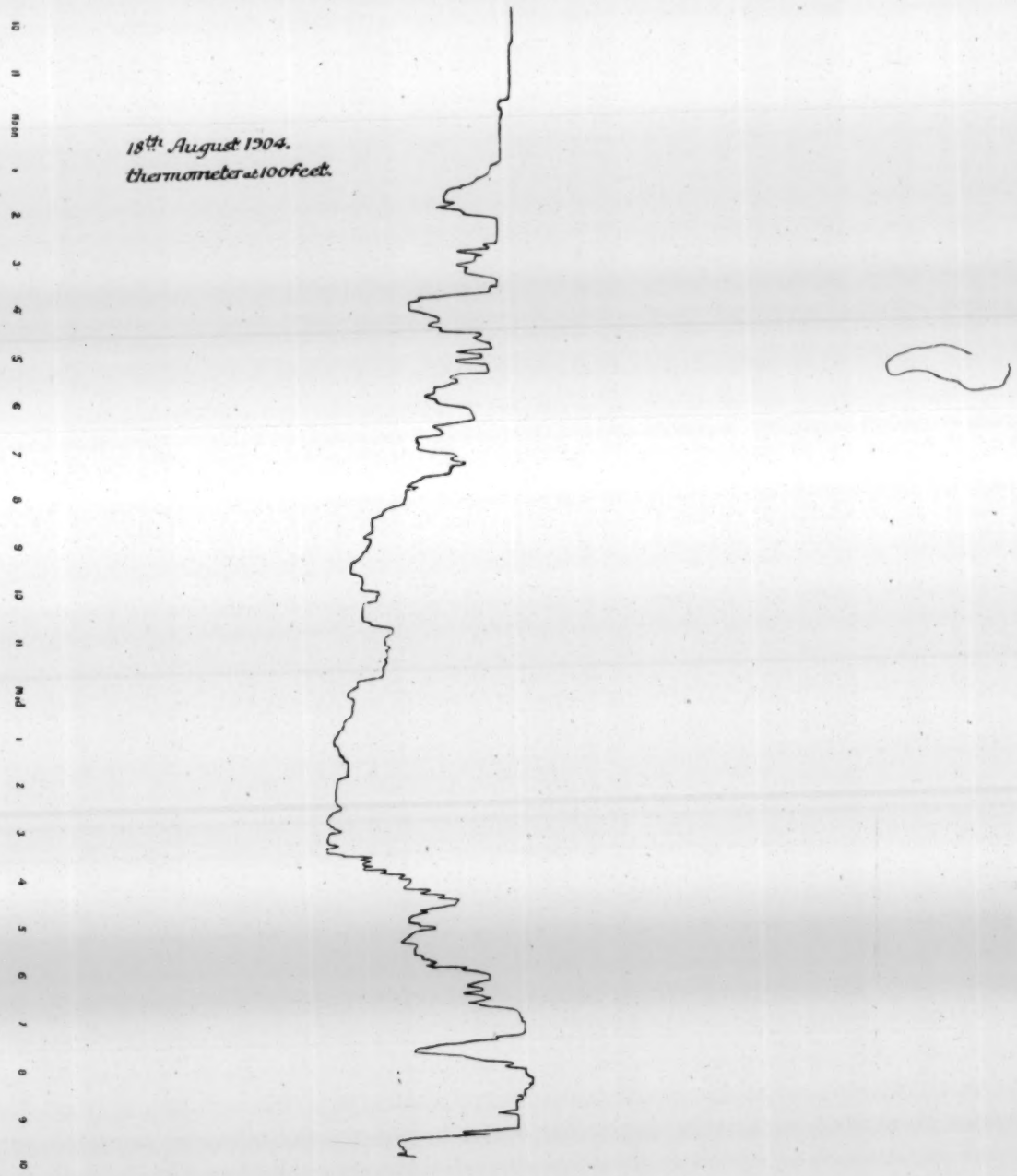

FIG. 15.*

depth—that is, in the neighbourhood of the *Sprungschicht*. Such rapid variations are quite natural, as convection currents must inevitably be set up where there are two layers of water of different temperatures in contact with one another, especially so in this case, as, owing to the presence of the temperature seiche, there is relative motion between the two layers.

* See footnote, page 423.

Sufficient has now been said to indicate what I consider to be the nature of the temperature changes which occur, particularly in Loch Ness, and in general in all similar lochs. I have not attempted to discuss in detail all the observations which were made in Loch Ness. Many of these were made without special object in view, and they are consequently difficult to discuss, and the present communication is made more with a view to suggest the lines of further investigation of lake temperatures than to give a detailed examination of particular phenomena. In the hope that further use may be made of the observations which have been made in Ness, the following tables have been arranged, giving the observations made in Loch Ness from July 1903 to April 1905.

APPENDIX

CONTAINING

TEMPERATURE OBSERVATIONS MADE IN LOCH NESS BY MEMBERS OF THE SCOTTISH LAKE SURVEY FROM 9TH JULY 1903 TO 24TH SEPTEMBER 1904,

AND

BY MEMBERS OF THE ORDER OF SAINT BENEDICT FROM 25TH SEPTEMBER 1904 TO 3RD MAY 1905.

EXPLANATION OF TABLES.

The Temperature Scale throughout is Fahrenheit. Where "Yacht" denotes the place of observation, the observation was made from the *Rhoda* (see page 410). The force of the wind is estimated on a scale of 0 – 6. Observations of Air Temperature were made by means of a sling thermometer. An interrogation mark (?) after an observation denotes that some doubt existed in the mind of the observer as to the correctness of his observation. A number appearing in brackets after an observation, *e.g.* 42·3 (500), indicates the depth at which the observation was made, being different from the depth denoted in the margin.

LOCH NESS.

Date	1903. July 9.	1903. July 10.	1903. July 11.	1903. July 13.	1903. July 14.	1903. July 15.	1903. July 16.	1903. July 18.	1903. July 20.	1903. July 21.	1903. July 22.	1903. July 23.
Time	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.	12 noon.
Position	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	SE. 2-3.	SE. 1.	SE. 1-3.	Variable.	SE. 1.	NE. 3-4.	NE. 1-2.	NE. 4.	E. 1.	SE. 1.	SE. 3.	SE. 1-4.
Air Temp.	59·0	55·5	58·4	56·2	66·4	57·0	54·2	53·4	58·0	59·5	60·4	63·4
Depth. Feet.												
0	46·2	48·9	52·1	53·0	56·2	52·5	53·1	52·8	55·0	55·9	54·5	59·0
5	...	...	...	...	51·8	...	..	...	...	54·9	...	...
10	...	...	52·0	50·4	50·2	...	52·0	...	53·0	54·2	...	53·0
20	...	...	49·8	...	...	...	...	...	...	52·5(15)	...	...
25	...	47·6	...	48·5	49·2	51·5	51·9	...	52·8	52·1	...	51·7
50	45·0	47·6	48·3	48·0	49·0	50·4	51·2	51·9	52·4	52·0	50·4	51·5
75	43·0	...	...	...	...	...	...	...	...	...	..	50·9
100	42·3	46·5	47·2	47·7	48·6	49·3	50·4	51·5	52·1	49·6	46·8	49·3
125	...	...	...	...	48·3	...	...	51·5	...	47·8	...	...
150	...	...	...	46·5	48·3	48·9	48·7	50·1	48·9	47·0	45·2	48·0
175	...	...	...	45·0	...	48·8	45·2	50·5	46·0	45·3	...	...
200	...	45·0	...	44·0	47·8	46·2	44·8	48·0	45·0	45·4	44·2	47·0
225	...	..	...	...	45·4	44·3	43·5	44·2(210)	...	...	...	46·1
250	...	...	46·0	42·5	43·9	43·2	42·8	...	43·2	44·8	43·0	44·9
275	...	...	...	...	...	...	...	42·8	...	...	...	...
300	42·0	43·5	45·3	42·5	42·9	42·2	42·6	42·6	42·4	43·9	42·3	43·7

Date	1903. July 24.	1903. July 24.	1903. July 25.	1903. July 25.	1903. July 25.	1903. July 25.	1903. July 27.	1903. July 27.	1903. July 27.	1903. July 27.	1903. July 28.	1903. July 28.
Time	4.30 p.m.	8.15 p.m.	7.30 a.m.	12 noon.	4.30 p.m.	8.30 p.m.	7.45 a.m.	12–1 p.m.	4–5 p.m.	9 p.m.	8 a.m.	3 p.m.
Position	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	SW.	SW.	Calm.	NE. 5.	..	SE. 5–6.	Calm.	Dead calm	NE. 1.	Calm.	NE. 1.	NE.
Air Temp.	64·8	..	58·2	63·4	..	..	55·5	63·0	55·8	..	53·4	..
Depth. Feet.												
0	53·7	54·2	55·0	54·4	57·0	55·0	56·3	59·0	54·5	...	55·6	...
5	...	...	52·6	54·5	55·5	54·1	54·5	55·4	54·5	55·2	54·9	54·8
10	..	...	52·0	54·5	54·1	54·5	54·1	54·5	54·2	54·0	54·9	54·6
15	..	...	50·9	53·9	53·8	54·3	53·8	53·9	53·2	53·1	54·7	...
25	50·5	50·5	50·8	51·1	53·0	53·6	52·9	53·1	52·7	52·7	54·5	54·6
50	49·8	49·5	49·9	50·0	50·5	52·4	51·5	51 6	50·8	51·0	52·0	53·6
75	49·0	...	...	...	...	...	...	...	...	...	...	...
100	48·5	48·5	48·8	48·7	49·0	49·8	49·5	49·5	48·9	48·9	49·9	51·0
150	48·0	47·7	47·6	47·6	48·0	49·0	48·7	47·8	49·0	51·0	45·6	48·8
200	46·3	44·8	44·6	44·5	44·4	48·0	43 9	43·6	43·2	48·9	43·4	44·3
225	44·2	...	...	...	...	...	...	...	...	...	...	...
250	43·3	42·8	42·8	42·8	42·8	45·3	42·6	42·8	...	46·0	42·6	43·0
300	42·8	42·8	42·4	42·4	42·4	42·8	42·4	42·4	42·4	...	42·4	...

Date	1903. July 28.	1903. July 29.	1903. July 29.	1903. July 30.	1903. July 30.	1903. July 31.	1903. July 31.	1903. Aug. 1.	1903. Aug. 1.	1903. Aug. 3.	1903. Aug. 3.	1903. Aug. 4.
Time	9 p.m.	8 a.m.	11–12 noon	8 a.m.	12 noon.	8 a.m.	9 p.m.	8 a.m.	5.30 p.m.	8 a.m.	7 p.m.	9.30 a.m.
Position	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	NE.	..	Calm.	Calm.	SSW.	S. 2.	SSW. 2.	S. 0–1.	Calm.	S.	S.	SSW. 1.
Air Temp.	55·6	54·0	58·9	57·0	..	58·1	..	..	..	..	..	..
Depth. Feet.												
0	54·8	55·3	58·9	57·1	57·5	54·5	52·8	53·2	54·3	50·3	51·8	51·6
5	...	55·3	55·4	55·9	56·5	54·5	...	51·2	...	50·3	50·9	...
10	55·1	55·2	55·2	55·5	55·2	54·5	52·5	50·9	50·5	50·4	49·8	50·5
15	55·0	55·0	55·0	55·2	55·1	54·4	52·0	50·7	50·2	50·0	49·7	50·2
25	55·0	54·7	54·9	54·7	54·9	51·4	50·6	50·4	49·6	49·5	49·5	50·0
30	...	...	...	...	54·8	51·4	...	...	...	...	...	...
35	...	...	...	54·9	54·3	...	...	..	...	...	...	...
45	...	..	...	...	51·2	...	...	...	...	...	...	...
50	55·0	55·1	55·1	51·7	51·4	50·6	50·7	50·0	49·5	49·3	49·2	50·1
90	...	...	...	49·2	...	...	...	...	...	...	...	...
100	51·2	51·0	51·2	...	48·4	48·4	50·1	48·7	48·5	48·7	48·7	49·1
150	49·4	49·3	49·3	45·6	45·1	45·1	47·3	47·3	48·0	46·4	47·7	47·5
190	...	...	...	44·3	...	...	...	...	...	...	...	...
200	46·3	47·8	46·7	...	44·1	43·9	45·1	46·4	47·2	44·3	45·3	44·0
225	...	...	...	...	...	...	...	...	45·7	...	...	...
250	43·3	43·9	44·4	43·3	43·4	43·7	43·4	45·9	45·0	43·2	43·6	42·8
290	...	...	...	42·8	...	...	...	...	...	...	...	...
300	42·6	42·8	43·3	...	42·6	42·6	42·8	45·1	44·2	42·6	42·6	42·6

Date	1903. Aug. 5.	1903. Aug. 5.	1903. Aug. 6.	1903. Aug. 6.	1903. Aug. 7.	1903. Aug. 8.	1903. Aug. 8.	1903. Aug. 8.	1903. Aug. 8.	1903. Aug. 8.	1903. Aug. 10.	1903. Aug. 10.
Time	8 a.m.	9 p.m.	8 a.m.	6 p.m.	7 a.m.	12 noon.	1.30 p.m.	3.30 p.m.	5.30 p.m.	9 p.m.	11.30 a.m.	12.30 p.m
Position	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Inver-morriston.	Foyers.	Half way between Urquhart and Dores.	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	S. 1.	SW.	S.	S.	S. 2.	NE. 1.	S. 0–1.	S. 2–3.	S. 5.	S. 3.	Calm.	Calm.
Air Temp.	..	..	..	55·0	..	56·0	66·0	62·5	63·5	63·0	55·0	..
Depth. Feet.												
0	52·1	52·9	51·9	52·0	52·5	53·0	54·1	54·9	55·3	53·2	53·5	53·7
10	49·1	49·2	50·6	51·5	51·5	51·9	51·9	54·1	55·2	52·8	53·5	53·4
15	48·9	48·9	50·0	50·7	51·0	51·6	...	...	...	52·3	53·0	53·0
25	48·4	48·6	49·6	49·6	49·8	51·8	...	...	...	...	52·5	52·4
40	...	48·5	...	...	...	...	...	...	...	...	...	...
45	...	48·3	...	...	...	...	...	...	...	..	..	...
50	48·5	47·9	49·7	49·8	49·6	50·7	51·8	53·0	54·1	51·8	50·8	50·9
55	...	47·9	...	...	...		...	...	...	...	...	...
75	...	46·7	...	...	...	...	...	...	...	...	...	...
80	...	46·4	...	...	...	...	...	...	...	...	...	...
100	46·6	46·6	49·5	49·4	49·4	50·5	50·9	50·0	50·0	50·7	49·7	49·5
110	..	...	..	...	...	...	...	...	...	...	...	49·0
125	...	...	...	...	...	...	...	..	...	...	.	47·0
140	..	...	...	...	...	...	...	...	...	...	...	44·6
150	44·6	44·0	49·1	48·0	47·2	49·5	...	...	46·9	50·4	44·7	44·7
175	...	...	48·7	...	...	..	...	...	...	...	...	...
200	42·8	43·0	48·6	46·2	45·0	48·0	46·8	...	42·6	49·0	43·5	43·6
250	42·4	42·6	46·9	44·2	43·5	45·1	...	...	...	46·7	42·8	42·8
275	...	...	44·9	...	...	...	...	...	...	...	...	...
300	42·4	42·4	43·9	42·6	42·6	43·2	43·7	43·0	42·8	43·9	42·5	42·7
400	...	...	...	...	...	...	42·4	42·3	42·6	...	...	...
600	...	...	...	...	...	...	42·3	42·3(500)	...	...	...	...
650	...	...	...	...	...	...	...	...	42·1	...	...	...

DATE	1903. Aug. 11.	1903. Aug. 12.	1903. Aug. 12.	1903. Aug 12.	1903. Aug. 12.	1903. Aug. 12.	1903. Aug. 12.	1903. Aug. 12.	1903. Aug. 13.	1903. Aug. 13.	1903. Aug. 13.	1903. Aug. 13.
TIME	8 a.m.	8 a.m.	3 p.m.	3.30 p.m.	4 p.m.	4.30 p.m.	5.30 p.m.	6 p.m.	8 a.m.	12 noon.	12.30 p.m.	1 p.m.
POSITION	Fort Augustus.	Fort Augustus.	In a Towards West Shore.	line from to Big Centre of Loch.	railings on Store. 120 yds. off East Shore.	railway Nearer in Shore.	In a line to mouth of Tarff.	In course of river Tarff, 200 yds. off.	Fort Augustus.	Same as at 3 p.m. on Aug. 12.	Same as at 3.30 p.m. on Aug. 12.	Same as at 4 p.m. on Aug. 12.
WIND	Calm.	Calm.	SW. 1–2.	SW. 1–2.	SW. 1–2.	SW. 1–2.	SW. 2.	SW. 2.	Calm.	S. 0–1.	SSW. 2.	SSW. 2–3.
AIR TEMP.	51·4	49·7	..	..	..	..	..	..	..	58·2	..	..
DEPTH. FEET.												
0	53·2	53·9	53·8	...	55·0	...	...	...	54·8	53·6	...	54·4
10	53·0	53·5	52·9	53·5	54·7	54·8	53·1	53·7	53·0	52 9	53·7	54·5
15	52·8	53·2	52·1	53·0	54·3	...	52·0	52·2	52·6	52·3	53·2	54·0
25	52·2	52·5	51·4	51·4	52·2	...	51·5	51·6	51·8	51·8	52·5	53·2
30	...	...	...	...	...	51·9	...	...	...	...	...	...
50	52·1	51·4	51·5	51·3	51·1	52·2(?)	51·4	51·2	51·8	52·1	51·9	51·9
100	51·0	49·8	48·9	48·8	47·7	...	48·2	48·4	50·9	50·7	50·8	50·5
150	50·0	46·6	45·6	45·4	45·6	...	45·0	44·4	50·1	49·2	49·1	49·3
200	49·0	44·5	43·7	44·1	43·5	...	...	...	49·1	46·9	47·3	46·9
225	...	...	...	...	...	...	...	...	48·3	...	...	...
250	45·0	43·0	42·8	42·8	42·8	...	...	...	47·0	46·5	45·9	...
300	43·3	42·7	...	42·6	...	...	...	...	44·4	...	44·4	...

DATE	1903. Aug. 14.	1903. Aug. 14.	1903. Aug. 14.	1903. Aug. 14.	1903. Aug. 15.	1903. Aug. 15.	1903. Aug. 15.	1903. Aug. 17.	1903. Aug. 17.	1903. Aug. 17.	1903. Aug. 17.	1903. Aug. 17.
TIME	8 a.m.	8 p.m.	8 p.m.	8.30 p.m.	8 a.m.	11.30 a.m.	1 p.m.	9.30 a.m.	11 a.m.	12.30 p.m.	2.30 p.m.	4 p.m.
POSITION	Fort Augustus.	Fort Augustus.	Off Canal, Fort Augustus. (Bottom 65 ft.)	Off Borlum.	Fort Augustus.	Port Clair.	1½ miles north of Inver-morriston.	Fort Augustus.	Inver-morriston.	S. of Foyers.	N. of Urquhart Castle.	3½ miles N. of Urquhart.
WIND	NE. 2.	NE. 2.	..	..	NE. 3.	NE. 1–2.	NE. 0–2.	SW. 0–1.	SW. 1–2.	SW. 2–3.	Calm.	Calm.
AIR TEMP.	..	..	..	..	..	58·9	..	55·5	58·0	57·2	57·5	..
DEPTH. FEET.												
0	54·3	54·5	57·0	54·5	54·5	54·4	54·4	53·5	53·7	54·1	54·9	55·7
10	53·5	53·7	54·0	53·1	53·7	53·9	53·4	53·5	53·5	54·1	54·8	55·5
15	53·0	53·6	53·3	53·2	53·7	...	...	53·4	...	...	...	...
25	52·3	53·2	...	...	...	53·5	53·0	53·1	53·6	53·8	54·3	55·1
35	...	...	53·1	...	...	...	...	...	...	...	...	...
50	52·4	53·2	52·6	...	53·3	53·5	53·3	53·4	53·5	53·7	53·5	54·8
55	...	...	52·7	...	...	...	...	...	...	...	...	...
100	50·8	53·2	...	...	53·2	53·0	53·0	50·3	51·0	50·9	51·8	51·6
150	47·0	52·9	...	...	53·0	51·7	50·3	47·5	46·1	46·6	48·3	48·4
165	...	52·3	...	...	...	...	...	...	...	...	...	...
200	45·2	46·0	...	...	45·9	46·0	45·5	45·5	45·1	43·7	44·6	44·8
225	...	...	...	...	44·3	...	...	...	...	...	...	...
250	43·2	43·9	...	...	43·4	...	...	43·2	...	...	...	...
300	42·8	42·8	...	...	42·9	43·0	43·1	42·8	43·1	42·8	42·8	42·8
400	...	...	...	...	...	42·4	42·6	...	42·5	42·6	42·4	42·4
550	...	...	...	...	..	42·3	42·3	...	42·3	42·3	42·3	42·4
600	...	...	...	...	.	...	...	...	...	...	42·5	...
650	...	...	..	...	.	...	...	...	...	...	42·5	...
700	...	...	...	...		...	...	...	...	...	42·1	...

Date	1903. Aug. 17.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 18.	1903. Aug. 19.	1903. Aug. 19.	1903. Aug. 19.	1903. Aug. 19.
Time	7.30 p.m.	9.30 a.m.	10.30 a.m.	12 noon.	2 p.m.	3 p.m.	4 p.m.	8 p.m.	9.30 a.m.	11 a.m.	12 noon.	2 p.m.
Position	Fort Augustus.	Fort Augustus.	Inver-morriston.	S. of Foyers.	N. of Urquhart Castle.	3½ miles N. of Urquhart Castle.	Aldourie.	Fort Augustus.	Fort Augustus.	Inver-morriston.	S. of Foyers.	Urquhart.
Wind	SW. 1-2.	Calm.	Calm.	NE. 1-2.	NE. 1-2.	NE. 2.	NE. 0-1.	NE. 0-1.	Calm.	SW. 2.	SW. 0-1.	SW. 2.
Air Temp.	54·4	53·6	56·0	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	53·1	53·9	55·0	55·1	56·2	56·0	55·6	55·2	55·1	54·5	55·7	56·1
10	53·3	53·4	53·5	54·1	55·3	55·9	55·5	55·4	54·6	53·5	55·3	55·7
15	53·0	53·0	...	...	...	...	55·3	55·0	54·5	...	...	...
25	52·3	52·5	53·1	53·7	54·7	55·5	55·0	54·0	53·8	53·2	54·1	54·8
50	52·3	52·2	53·1	53·5	54·4	54·8	55·0	53·3	53·5	53·2	53·5	54·2
100	50·5	50·5	51·0	52·5	53·0	50·6	50·7	51·6	50·7	50·9	50·3	51·0
150	49·0	48·9	48·5	48·2	48·0	47·9	...	49·7	46·9	47·5	47·7	48·5
200	48·7	47·6	47·1	46·1	44·5	44·0	...	46·8	44·5	45·5	46·1	46·5
250	47·4	46·4	...	...	...	...	...	44·6	43·1	...	...	...
300	47·0	44·1	43·3	43·3	42·8	42·7	...	43·1	42·8	43·0	43·4	43·1
400	...	...	42·5	42·4	42·4	42·4	...	...	...	42·6	42·8	42·6
550	...	..	42·4	42·3	42·3	42·2	...	...	...	42·3	42·4	42·3
700	...	...	...	...	42·2	...	...	...	...	...	...	42·1

Date	1903. Aug. 19.	1903. Aug. 19.	1903. Aug. 20.	1903. Aug. 20.	1903. Aug. 20.	1903. Aug. 21.	1903. Aug. 21.	1903. Aug. 22.	1903. Aug. 22.	1903. Aug. 22.	1903. Aug. 24.	1903. Aug. 24.
Time	3 p.m.	7 p.m.	8 a.m.	4 p.m.	5 p.m.	8 a.m.	6 p.m.	8 a.m.	2 p.m.	7 p.m.	10 a.m.	11 a.m.
Position	3½ miles N. of Urquhart.	Fort Augustus.	Fort Augustus.	Fort Augustus.	S. of Inver-morriston.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus off Monastery	Portclair.
Wind	SW. 2-3.	Calm.	Calm.	SW. 1.	SW. 1.	SSE. 1-2.	SSE. 1-3.	S. 1-2.	S. 3-4.	SW. 2.	NE. 3.	NE. 3.
Air Temp.	..	..	..	..	..	..	..	..	..	54·0	..	...
Depth. Feet.												
0	56·2	55·2	54·3	54·5	54·0	54·4	55·0	54·0	53·0	52·4	54·8	53·7
5	...	...	...	...	...	...	...	...	53·2	...	...	...
10	56·2	54·5	54·4	54·6	54·5	54·4	54·0	52·8	53·0	52·2	53·5	53·7
15	...	54·0	54·2	54·2	54·2	54·0	...	52·6	52·5(20)	50·5	53·0	...
25	54·5	53·6	53·4	53·2	54·0	53·6	53·1	52·2	...	49·4	52·9	53·5
30	...	...	.	...	...	...	...	...	52·0	...	...	...
40	...	...	...	...	...	...	...	...	50·6	...	...	...
50	54·2	53·1	52·5	52·6	53·4	53·2	52·8	51·3	50·5	48·5	53·0	52·5
60	...	...	...	...	...	...	...	...	50·0	...	...	...
70	...	...	...	...	...	...	...	...	50·1	...	...	...
80	...	...	...	...	...	...	...	...	49·7	..	...	...
90	...	...	...	...	...	...	...	...	49·0	...	...	...
100	51·0	51·0	50·7	50·1	51·7	52·5	51·8	49·1	...	47·3	50·7	51·4
150	49·3	47·0	46·6	46·6	...	48·5	46·8	47·1	...	45·2	...	50·6
200	46·0	44·1	44·0	44·1	44·7	45·7	44·2	44·9	...	43·9	...	48·0
250	...	43·0	42·9	42·8	...	43·2	43·0	43·3	...	42·8	...	...
300	42·8	42·6	42·7	42·8	43·0	42·8	42·8	42·8	...	42·8	...	43·5
400	42·4	...	...	...	42·5	...	..	...	...	...	...	42·8
550	42·3	...	...	...	...	...	...	...	...	...	...	42·3
600	...	...	...	...	42·3	...	...	...	...	...	...	...

Date	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 24.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 25.
Time	12.30 p.m.	1.30 p.m.	2.30 p.m.	4.30 p.m.	5.30 p.m.	6.15 p.m.	6.30 p.m.	6.50 p.m.	7 p.m.	9 a.m.	9.30 a.m.	9.40 a.m.
Position	South of Alt Sigh.	Foyers Pier.	Lenie.	Half way between Urquhart and Abriachan.	Dores.	N. of Aldourie.	N. of Bona.	Middle of L. Dochfour.	Weir at end of Dochfour.	At Weir.	Middle of Dochfour.	N. of Bona.
Wind	NE. 2.	NE. 2.	NE. 3.	NE. 2.	NE. 2.	NE. 1-2.	NE. 1.	NE. 1.	Calm.	W. 1.	W. 1.	Calm.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	53·6	54·7	55·0	54·9	55·4	55·0	54·5	55·5	55·6	54·7	54·8	55·0
10	53·8	54·5	54·9	54·8	55·3	55·1	54·5	55·6	55·0	54·7	54·6	54·8
15	...	...	...	...	55·0	55·0	...	...	...	...	...	...
20	...	...	...	...	...	...	54·5	...	55·1	54·7	...	54·5
25	53·8	54·4	54·6	54·6	54·9	54·5	...	55·2	...	...	54·5	...
40	...	...	...	...	...	...	...	...	...	...	54·5	...
45	...	...	...	...	...	...	...	54·7	...	...	...	...
50	53·4	54·5	54·4	54·3	55·2	54·5	...	...	...	...	...	...
75	...	...	...	...	...	54·0	...	...	...	...	...	...
100	51·9	51·5	54·4	51·6	49·9	49·1	...	...	...	...	...	...
150	49·6	47·4	47·5	46·7	47·8	...	...	...	...	...	...	...
200	46·7	45·6	44·7	44·2	44·8	...	...	...	...	...	...	...
250	...	44·8	...	...	42·8	...	...	...	...	...	...	...
300	43·3	43·5	42·8	42·8	42·6	...	...	...	...	...	...	...
400	42·8	42·4	42·8	42·4	...	...	...	...	...	...	...	...
550	42·4	...	42·3	42·3	...	...	...	...	...	...	...	...

Date	1903. Aug. 25.	1903. Aug. 25.	1903 Aug. 25.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 25.	1903. Aug. 26.	1903. Aug. 26.	1903. Aug. 27.
Time	10 a.m.	11 a.m.	11.15 a.m.	12 noon.	1.30 p.m.	3 p.m.	4 p.m.	5.30 p.m.	6.30 p.m.	8 a.m.	6 p.m.	8 a.m.
Position	N. of Aldourie.	Dores.	In Dores Bay.	Between Urquhart and Abriachan.	Lenie.	Foyers.	S. of Alt Sigh.	Portclair.	Off Monastery	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	SW. 1.	Calm.	..	SW. 1.	SW. 1-2.	Calm.	SW. 1.	SW. 1.	SW. 1.	S. 1.	S. 1-2.	SW. 2-3.
Air Temp.	..	..	..	..	..	..	..	..	..	52·5	..	..
Depth. Feet.												
0	55·0	55·7	55·1	56·4	56·5	55·7	55·6	54·9	57·5	54·0	55·3	52·5
10	55·0	55·5	54·5	55·5	56·0	55·4	55·5	54·7	53·6	54·3	53·5	52·0
15	54·7	55·1	...	...	...	...	...	...	53·4	54·0	53·0	51·7
25	54·7	54·9	54·3	53·9	54·9	54·3	54·0	54·0	53·2	53·2	52·9	50·7
50	54·2	53·7	53·6	53·5	54·3	53·4	53·3	53·5	53·4	53·3	52·6	48·5
75	53·0	...	...	...	...	...	...	...	53·1	...	...	...
100	...	50·5	...	53·3	52·5	51·5	51·9	52·1	50·7	52·5	50·5	46·5
125	...	...	...	...	...	...	...	...	...	...	47·0	...
150	...	48·6	...	47·9	48·6	48·7	47·5	47·1	...	47·2	45·9	43·9
200	...	47·4	...	46·4	45·2	45·0	44·6	44·0	...	44·3	43·3	43·1
250	...	45·9	...	...	..	44·1	...	...	...	42·8	42·8	42·7
300	...	44·6	...	43·2	43·0	42·5	42·8	42·8	...	42·4	42·6	42·6
400	...	...	...	42·4	42·5	42·2	42·4	42·4	...	...	...	...
550	...	...	...	42·2	42·4	...	42·2	42·3	...	...	...	...

Date	1903. Aug. 28.	1903. Aug. 28.	1903. Aug. 28.	1903. Aug. 28.	1903. Aug. 28.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.
Time	8 a.m.	6 p.m.	6.30 p.m.	7 p.m.	7 p.m.	8 a.m.	8.30 a.m.	11 a.m.	12 noon.	..	..	..
Position	Fort Augustus.	Fort Augustus.	Opposite old Pier in middle of Loch.	In Borlum Bay.	Near Shore in Borlum Bay.	Fort Augustus.	Opposite old Pier.	Portclair.	Inver-morriston.	Inver-morriston East Shore.	Inver-morriston West Shore.	1½ miles north of Inver-morriston.
Wind	S. 1-5.	S. 3.	..	..	..	SW. 1-2.	..	SW. 0-2.	..	..	..	Variable.
Air Temp.	50·2	..	..	..	..	..	..	53·4	54·0	..	..	..
Depth. Feet.												
0	46·2*	47·0	47·0	45·5	43·9	50·8	49·9	51·3	52·3	51·8	52·9	53·5
3	...	...	...	...	44·1	...	...	...	...	...	...	...
10	45·6	46·4	47·3	...	46·6(7)	50·4	50·0	51·3	52·3	51·6	51·7	52·7
15	45·2	46·0	...	...	...	50·1	...	...	...	...	...	...
25	45·0	45·3	45·2	45·5	...	49·8	49·9	50·9	51·9	...	...	52·9
50	44·7	44·5	45·5†	44·9	...	49·8	49·1	50·6	51·4	50·5	51·8	52·0
100	43·4	43·4	43·5	43·7	...	48·4	48·5	49·7	50·4	49·1	51·4	50·5
150	43·0	43·0	43·1	...	...	46·0	...	...	49·9	...	...	48·8
200	43·0	43·0	42·8	...	...	48·0	46·0	46·0	48·9	...	...	47·6
250	...	42·6	...	...	...	46·8	...	...	...	...	...	...
265	42·6	...	...	...	...	..	...	...	...	...	...	...
300	42·4	42·6	...	...	...	46·0	...	46·2	42·8	...	...	44·0
400	...	...	...	...	...	...	...	45·7	42·8	...	...	42·8
500	...	...	...	...	...	...	...	43·8	...	...	...	...
550	...	...	...	...	...	...	...	42·8	42·4	...	...	42·4

* A strong southerly wind had been blowing for a considerable time.
† A reading taken shortly before was 46·3.

Date	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 29.	1903. Aug. 31.	1903. Aug. 31.	1903. Aug. 31.	1903. Aug. 31.	1903. Aug. 31.	1903. Aug. 31.	1903. Aug. 31.	1903. Sept. 1.	1903. Sept. 1.
Time	..	..	6 p.m.	8 a.m.	11 a.m.	12.30 p.m.	1.15 p.m.	2 p.m.	3.30 p.m.	8 p.m.	8 a.m.	11 a.m.
Position	1½ miles north of Inver-morriston West Shore.	1½ miles north of Inver-morriston East Shore.	Fort Augustus.	Fort Augustus.	Portclair.	Inver-morriston.	1½ miles north of Inver-morriston.	S. of Foyers.	Inver-farigaig.	Fort Augustus.	Fort Augustus.	East side of Borlum Bay. Bottom 84.
Wind	..	..	..	NE. 0-1.	..	..	..	..	..	..	S. 5-7.	S. 3-4.
Air Temp.	..	..	..	..	55·7	55·0	..	56·1	..	..	..	..
Depth. Feet.												
0	53·1	53·6	51·3	52·5	51·4*	51·5*	53·6	54·5	54·3	53·1	53·2	53·1
10	52·6	53·5	51·5	52·5	53·2	53·4	53·4	53·9	54·4	...	53·5	...
15	...	...	51·2	52·5	...	...	...	...	...	...	53·2	...
25	...	...	50·7	52·3	53·0	53·0	53·0	53·3	53·9	...	53·2	53·0
50	52·3	51·7	51·0	52·0	52·7	52·5	53·0	53·4	53·9	52·5	53·2	52·8
75	...	...	...	...	...	...	...	...	...	...	...	52·3
100	50·4	49·1	50·2	50·5	50·9	51·0	51·2	52·1	52·0	...	51·5	...
150	...	...	49·9	...	46·8	49·9	49·2	49·6	50·0	50·2	50·4	...
200	...	...	49·2	43·0	44·0	45·0	45·0	45·8	46·1	...	49·1	...
250	...	...	48·9	...	...	...	...	...	...	43·3	47·0	...
300	...	...	48·6	42·6	43·2	43·3	43·3	43·6	43·3	...	43·4	...
400	...	..	...	...	42·9	43·0	43·1	43·2	42·8	...	...	...
550	...	...	...	...	42·7	42·8	42·9	43·0	42·7	...	...	...

* Two observations confirmed this low surface temperature.

Date	1903. Sept. 1.	1903. Sept. 1.	1903. Sept. 2.	1903. Sept. 2.	1903. Sept. 2.	1903. Sept. 2.	1903. Sept. 2.	1903. Sept. 2.	1903. Sept. 3.	1903. Sept. 3.	1903. Sept. 4.	1903. Sept. 4.
Time	11 a.m.	7 p.m.	8 a.m.	11 a.m.	11.45 a.m.	1 p.m.	3 p.m.	4 p.m.	8 a.m.	6 p.m.	8 a.m.	7 p.m.
Position	Middle of Borlum Bay, off Tarff.	Fort Augustus.	Fort Augustus.	Portclair.	Inver-morriston.	S. of Foyers.	Urquhart Castle.	S. of Abriachan.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.
Wind	S. 3–4.	S. 4–5.	Calm.	Calm.	Calm.	NE. 1.	NE. 2.	NE. 1–2.	Calm.	S. 1–2.	Calm.	S. 3–4.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	52·0	51·6	51·6	53·1	53·2	53·3	53·0	52·9	52·4	52·1	52·0	51·8
10	...	51·6	51·6	52·2	52·3	52·7	52·5	52·5	52·4	52·0	51·9	51·8
15	...	51·6	51·7	...	...	...	...	...	52·2	52·0	51·9	...
25	52·0	51·4	51·4	52·3	52·5	52·5	52·5	52·7	51·8	52·0	51·8	51·8
50	51·9	51·0	51·2	50·9	50·9	51·7	52·5	...	51·6	51·2	51·4	50·9
75	51·8	...	...	...	...	...	...	...	...	...	...	...
100	53·0(?)	49·5	48·7	47·0	45·5	51·3	52·0	52·4	51·5	50·4	50·4	47·8
140	51·3	..	...	...	...	...	...	...	...	...	...	...
150	...	46·0	45·0	45·1	44·4	49·6	51·8	...	50·9	49·1	48·2	44·7
180	50·3	...	...	...	...	...	...	...	...	...	...	...
200	...	43·4	43·8	43·3	43·6	47·9	47·2	...	50·3	47·4	45·1	43·5
250	...	43·2	43·3	...	...	...	...	...	49·5	45·1	43·3	43·0
300	...	43·2	43·1	43·1	43·3	43·6	43·8	...	48·2	43·3	42·8	42·8
400	...	...	...	43·0	42·9	43·0	42·8	43·2	...	...	...	...
550	...	...	...	42·8	42·8	43·1	42·6	...	...	...	...	...

Date	1903. Sept. 5.	1903. Sept. 5.	1903. Sept. 7.	1903. Sept. 7.	1903. Sept. 8.	1903. Sept. 8.	1903. Sept. 9.	1903. Sept. 9.	1903. Sept. 10.	1903. Sept. 10.	1903. Sept. 10.	1903. Sept. 10.
Time	8 a.m.	6 p.m.	8 a.m.	5 p.m.	8 a.m.	6 p.m.	8 a.m.	7 p.m.	8 a.m.	11 a.m.	12 noon.	1 p.m.
Position	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Portclair.	North of Inver-morriston.	S. of Foyers.
Wind	S. 2–3.	S. 2–4.	SW. 2–3.	SW. 2–4.	SW. 1–2.	SW. 0–1.	S. 1.	SW. 1–3.	S. 2–3.	SW. 2.	SW. 2.	SW. 2.
Air Temp.	63·0	..	..	..	..	..	48·5	48·0	47·8	..	..	..
Depth. Feet.												
0	52·3	51·9	50·2	50·9	51·0	50·9	50·9	51·3	51·0	51·0	51·2	51·9
10	52·2	52·1	50·4	50·7	50·8	51·0	50·7	51·4	51·4	51·0	51·4	51·7
15	...	...	...	...	...	...	50·5	51·1	...	...	...	...
25	51·7	...	49·6	50·0	50·4	50·7	50·6	51·2	51·1	51·0	51·3	51·6
50	51·5	51·4	...	50·0	50·4	50·5	50·4	51·0	51·2	50·8	51·2	51·7
90	...	...	...	49·9	...	...	...	...	...	...	...	...
100	51·4	50·5	47·9	...	49·5	48·4	50·1	50·5	50·4	50·4	50·4	51·3
150	50·6	50·2	46·4	49·4	48·0	46·3	48·7	50·4	48·9	49 5	49·5	50·7
200	50·4	43·1	44·6	48·4	...	44·7	46·6	49·9	45·3	46·2	46·7	46·2
250	48·7	44·8	43·1	47·3	44·3	43·3	44·6	48·9	43·3	...	...	...
290	...	...	...	44·8	...	...	...	...	...	...	...	...
300	46·4	43·1	43·0	...	43·1	42·9	43·3	46·2	43·0	43·1	43·2	43·4
400	...	...	...	...	...	...	...	...	...	42·9	42·8	43·2
550	...	...	...	...	...	...	...	...	...	42·7	42·5	42·6

Date	1903. Sept. 10.	1903. Sept. 10.	1903. Sept. 11.	1903. Sept. 12.	1903. Sept. 12.	1903. Sept. 12.	1903. Sept. 12.	1903. Sept. 12.	1903. Sept. 14.	1903. Sept. 15.	1903. Sept. 15.	1903. Sept. 15.
Time	3 p.m.	6 p.m.	8 a.m.	8 a.m.	12 noon.	3 p.m.	3.30 p.m.	4 p.m.	8 a.m.	7 a.m.	9.30 a.m.	10.30 a.m.
Position	Urquhart.	Off Monastery.	Fort Augustus.	Fort Augustus.	Fort Augustus.	Portclair.	Inver-morriston.	Fassie Point.	Fort Augustus.	At Yacht.	At Bona.	Abriachan.
Wind	SW. 3.	Calm.	Calm.	Calm.	NE. 1.	NE. 2–3.	Calm.	Calm.	S. 0–½.	S. ½	SW. 3–4.	SW. 4.
Air Temp.	..	..	..	..	..	..	..	..	41·0	39·5	..	..
Depth. Feet.												
0	52·3	...	51·3	51·4	51·3	51·4	51·7	52·0	51·4	51·4	51·7	51·9
10	52·4	51·4	51·3	51·4	51·4	51·5	51·6	52·1	51·1	51·4	51·9	52·0
15	...	51·2	50·9	...	...	...	...	...	51·2	...	...	...
25	52·4	...	51·2	51·0	50·9	51·4	51·2	52·1	51·1	51·4	51·9	51·9
45	...	...	...	...	...	...	...	...	...	...	...	51·7
50	52·4	50·9	50·7	51·0	51·2	51·4	51·4	51·4	51·1	51·4	51·7	...
100	52·2	49·5	50·3	50·6	50·8	50·9	50·9	51·4	51·1	51·0	51·6	51·9
150	51·8	48·0	47·3	50·6	50·6	50·5	50·6	50·2	51·1	49·6	...	50·4
200	48·6	45·0	44·1	50·2	50·0	48·6	47·5	47·0	51·1	44·2	...	49·5
250	...	43·8	43·2	44·2	44·2	...	...	...	43·9	...	...	...
300	43·8	43·0	42·9	43·3	43·3	43·1	43·0	43·0	43·1	...	...	43·5
400	42·9	...	...	...	...	42·8	42·8	42·9	...	...	...	...
550	42·5	...	...	...	...	42·8	42·7	42·6	...	...	...	...
700	...	...	...	...	...	...	...	42·4	...	...	...	...

Date	1903. Sept. 15.	1903. Sept. 15.	1903. Sept. 15.	1903. Sept. 15.	1903. Sept. 15.	1903. Sept. 16.	1903. Sept. 17.	1903. Sept. 18.	1903. Sept. 21.	1903. Sept. 19.	1903. Sept. 22.	1903. Sept. 22.
Time	11.30 a.m.	1 p.m.	2.30 p.m.	4 p.m.	6 p.m.	8 a.m.	8 a.m.	8 a.m.	8 a.m.	8 a.m.	10 a.m.	2 p.m.
Position	1 mile north of Temple.	Lenie.	Foyers.	Inver-morriston.	Fort Augustus.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Fort Augustus.
Wind	SW. 4.	..	SW. 3.	SW. 1-2.	SW. 0–1.	Calm.	Calm.	Calm.	NE. 5.	NE. 2.	NE. 1.	..
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	60·8
Depth. Feet.												
0	52·3	52·2	52·0	52·0	52·0	51·2	51·4	51·4	52·0	51·4	52·1	52·4
10	52·1	52·2	52·0	52·0	51·5	51·4	51·4	51·0	52·0	...	...	52·3
25	52·0	52·0	52·0	51·9	51·4	51·4	51·4	51·0	51·9	51·3	52·1	52·2
50	52·0	51·6	51·5	51·3	51·2	51·3	51·4	50·3	51·9	51·2	52·1	52·0
100	51·8	51·3	51·1	50·9	51·1	51·0	51·2	49·0	51·8	51·0	51·9	52·0
140	...	...	...	...	...	...	...	...	...	...	...	51·7
150	51·0	50·1	50·5	48·3	45·0	50·5	50·0	46·0	49·9	50·5	51·9	51·9
200	47·1	48·1	46·7	44·5	44·0	45·0	48·7	44·2	44·9	49·8	46·4	48·1
230	...	...	...	...	...	...	...	...	...	...	44·0	44·6
250	...	...	...	43·9	43·1	44·0	...	...	...	...	...	43·8(235)
300	43·4	43·8	43·5	...	43·4	...	...	...	...	...	...	...
350	...	...	...	43·1	...	...	...	...	...	...	...	...
400	43·1	43·1	43·1	...	...	...	...	...	...	...	...	...
550	42·9	42·9	...	...	...	...	...	...	...	...	...	...
700	42·5	...	...	...	...	...	...	...	...	...	...	...

Date	1903. Sept. 22.	1903. Sept. 22.	1903. Sept. 22.	1903. Sept. 22.	1903. Sept. 23.	1903. Sept. 24.	1903. Sept. 24.	1903. Sept. 24.	1903. Sept. 25.	1903. Sept. 25.	1903. Sept. 25.	1903. Sept. 25.
Time	2 p.m.	3.30 p.m.	5.30 p.m.	6 p.m.	3 p.m.	4 p.m.	4 p.m.	4 p.m.	11 a.m.	11 a.m.	11 a.m.	5.30 p.m.
Position	Abriachan.	Urquhart.	Foyers.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Foyers.	Yacht.	Portclair.	Foyers.	Yacht.
Wind	Calm.	SW. 2.	SW. 1.	..	S. 1-2.	Calm.	Calm.	Calm.	Calm.	Calm.	..	..
Air Temp.	..	..	..	57·8	..	63·0	..	..	53·0	..	..	..
Depth. Feet.												
0	52·2	52·3	52·0	52·7	53·4	54·0	55·0	53·3	52·9	52·7	52·5	...
10	52·6	52·3	52·0	52·2	...	52·8	52·8	52·5	52·0	52·2	52·3	...
20	...	...	...	...	52·3	...	...	...	...	...	...	...
25	52·6	52·1	51·9	52·2	...	52·1	52·3	...	52·0	51·9	...	...
50	52·1	52·1	51·3	52·0	52·0	52·0	52·0	51·5	52·0	51·9	51·7	...
75	...	...	...	...	52·0	...	...	...	...	...	...	...
100	51·8	51·9	51·1	52·0	52·0	52·0	51·7	51·0	50·9	51·4	51·2	50·2
125	...	...	...	...	52·0	...	...	...	...	...	...	...
140	...	...	...	...	51·3	...	...	...	...	...	...	...
150	49·9	49·2	49·1	51·8	49·6	48·5	50·0	51·0	48·6	48·6	51·0	48·5
160	...	...	...	...	48·4	...	...	...	...	...	...	...
180	...	...	...	...	47·0	47·0	...	...	47·3	...	...	47·5
200	46·2	46·2	44·4	46·3	...	46·2	46·0	46·3	46·2	46·5	46·1	46·0
230	...	...	...	43·8	...	45·0(240)	...	...	44·4(235)	...	...	44·2(235)
300	43·6	43·2	43·2	...	...	...	43·3	43·0	...	43·2	43·0	...
400	42·8	43·1	43·2	...	...	...	43·0	42·6	...	42·9	42·6	...
500	42·8	43·0	43·0	...	...	...	42·7	...	...	42·7	...	...
550	...	...	...	...	...	...	...	42·5	...	...	42·5	...
600	...	...	...	...	...	...	42·5	...	...	...	...	...
650	...	...	42·8	...	...	...	...	...	...	...	...	...
700	42·6	42·6	...	...	...	...	...	...	...	...	...	...

Date	1903. Sept. 26.	1903. Sept. 26.	1903. Sept. 26.	1903. Sept. 26.	1903. Sept. 26.	1903. Sept. 29.	1903. Sept. 29.	1903. Sept. 30.	1903. Sept. 30.	1903. Oct. 1.	1903. Oct. 2.	1903. Oct. 5.
Time	7 a.m.	11 a.m.	11 a.m.	11 a.m.	4 p.m.	12 noon.	5.30 p.m.	6 a.m.	6 p.m.	7 a.m.	1 p.m.	11.30 a.m.
Position	Yacht.	Yacht.	Portclair.	Foyers.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SW. 1.	Calm.	..	SW. 1.	SSW. 1.	SSW. 3.	Calm.	SW. 1.	Calm.	SW. 1.	SW. 4.
Air Temp.	46·0	60·0	..	..	60·0	..	..	..	57·0	54·0	58·6	49·4
Depth. Feet.												
0	53·2	53·5	53·4	54·0	52·5	52·3	51·6	52·8	51·5	51·3	51·8	51·6
10	...	...	52·6	52·4	...	...	...	...	...	...	...	...
25	52·1	52·1	52·0	...	52·0	51·7	51·3	51·5	51·2	51·0	51·1	...
50	52·0	52·0	52·0	51·5	52·0	51·2	51·0	51·3	51·0	51·0	51·0	...
100	51·1	50·9	51·3	51·1	50·5	51·0	51·0	51·0	50·6	50·6	51·0	51·4
150	49·8	50·0	49·3	50·8	49·9	49·6	49·8	50·1	49·6	49·6	50·6	...
200	47·9	48·2	47·2	45·1	47·7	44·3	46·4	45·8	...	45·2	45·6	44·1
240	45·0	44·9	...	...	45·0	43·5	44·0	44·3	...	44·2	44·0	43·5
300	...	...	43·7	43·0	...	...	...	...	...	...	...	...
400	...	...	43·0	...	...	...	...	...	...	...	...	...
500	...	...	42·8	...	...	...	...	...	...	...	...	...
550	...	...	...	42·5	...	...	...	...	...	...	...	...
600	...	...	42·7	...	...	...	...	...	...	...	...	...

Date	1903. Oct. 5.	1903. Oct. 6.	1903. Oct. 6.	1903. Oct. 7.	1903. Oct. 7.	1903. Oct. 7.	1903. Oct. 8.	1903. Oct. 8.	1903. Oct. 9.	1903. Oct. 9.	1903. Oct. 10.	1903. Oct. 10.
Time	5 p.m.	9.30 a.m.	5 p.m.	9.30 a.m.	2.30 p.m.	4 p.m.	9 a.m.	5 p.m.	9 a.m.	4 p.m.	10.30 a.m.	1 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	..	NE. 3.	NE.	Calm.	NE. 2.	NE. 1.	NE. 2.	NE. 2.	NE. 2.	NE. 3.	Calm.	NE. 1.
Air Temp.	..	47·0	45·0	41·0	46·9	48·5	46·5	46·5	45·3	45·5	35·0	46·8
Depth. Feet.												
0	51 6	51·2	51·2	51·2	51·4	51·0	51·2	51·0	51·0	51·0	51·0	51·1
50	...	51·1	...	51·2	51·2	...	51·2	...	...	51·0	51·0	51·0
100	51·2	51·2	...	51·2	51·2	...	47·8	...	...	51·0	50·9	50·7
150	...	51·2	51·2	51·2	51·2	...	47·8	...	...	51·0	50·0	50·2
175	...	...	...	...	48·9	...	...	...	...	...	...	...
190	...	...	...	...	...	48·7	...	...	...	...	...	...
200	43·5	47·5	49·4	50·2	48·4	48·4	...	...	51·0	51·0	48·4	44·2
210	...	...	...		...	47·1	43·9	44·3	...	51·0	44·7	44·2
225	...	...	46·7	48·2	48·2	...	...	43·0	50·9	50·8	44·4	43·7
240	43·1	43·7	46·2(230)	...	48·0	47·3	43·3	43·1	50·8	50·8(235)	...	43·3
250	...	...	...	48·2	...	...	...	...	...	...	43·9	...

Date	1903. Oct. 12.	1903. Oct. 12.	1903. Oct. 13.	1903. Oct. 13.	1903. Oct. 14.	1903. Oct. 14.	1903. Oct. 15.	1903. Oct. 15.	1903. Oct. 16.	1903. Oct. 17.	1903. Oct. 17.	1903. Oct. 17.
Time	9.30 a.m.	2.30 p.m.	9 a.m.	4.30 p.m.	9 a.m.	4.30 p.m.	10 a.m.	3.30 p.m.	5 p.m.	8 a.m.	8.30 a.m.	8.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Between Tarff and Yacht.	Yacht.	Between Yacht and Glendoe.
Wind	NE. 1.	NE. 1.	SW. 0–2.	SW. 0–1.	SW. 0–1.	SW. 0–1.	SW. 2.	SW. 3.	SW. 0–1.	..	..	..
Air Temp.	50·5	..	47·5	..	42·0	44·7	..	..	..	..	..	..
Depth. Feet.												
0	50·6	...	50·7	50·6	50·2	49·8	49·4	48·7	45·5	48·7	48·8	49·0
10	...	...	...	...	...	...	...	...	...	48·7	...	...
50	50·6	50·7	50·6	50·6	49·4	49·2	49·4	48·4	44·6	48·7	...	48·6
100	50·6	50·7	50·7	49·4	48·7	47·5	48·9	48·0	43·5	...	48·7	48·3
130	...	...	49·6	...	...	...	...	...	...	...	...	...
150	50·5	50·6	48·0	47·3	47·1	46·7	48·9	48·0	43·1	48·7	...	...
160	...	...	...	...	45·8	...	...	...	...	...	...	...
175	...	...	...	...	44·6	...	...	...	...	...	...	...
195	...	...	46·7	...	43·9(190)	...	...	...	...	...	...	...
200	50·1	50·4	46·5	44·4	43·7	43·3	46·9	46·5	43·0	...	...	...
210	...	48·2	...	...	...	...	...	...	...	...	...	...
225	45·4	45·3	44·4	...	43·5	43·3	46·9	45·7	42·8	...	...	...
230	45·5	...	43·9		...	...	...	...	...	...	...	...
250	...	...	...	43·4(240)	43·5	43·1(245)	46·9	45·2	42·8	...	48·6	48·2
255	...	...	43·5	...	...	...	...	...	...	...	...	...
400	...	...	...	...	...	...	...	...	...	...	...	46·7

Date	1903. Oct. 17.	1903. Oct. 17.	1903. Oct. 17.	1903. Oct. 17.	1903. Oct. 17.	1903. Oct. 19.	1903. Oct. 19.	1903. Oct. 20.	1903. Oct. 20.	1903. Oct. 21.	1903. Oct. 22.	1903. Oct. 22.
Time	9.30 a.m.	9.30 a.m.	11 a.m.	1 p.m.	3 p.m.	10 a.m.	4 p.m.	10 a.m.	4.30 p.m.	10.30 a.m.	10 a.m.	4 p.m.
Position	Glendoe.	Halfway between Oich and Railway Pier.	Portclair.	S. of Foyers.	Urquhart.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	..	..	Calm.	NNE. 1.	NNE. 1.	Calm.	SW. 1.	SW. 0–½.	SW. 0–1.	..	SW. 0–½.	..
Air Temp.	..	..	..	..	..	58·0	54·0	52·0	53·0	..	..	..
Depth. Feet.												
0	49·1	49·1	49·8	50·4	50·4	49·6	49·6	49·6	49·4	49·3	48·9	48·7
50	49·0	...	49·6	...	...	49·2	49·3	49·1	49·1	49·1	48·7	48·4
100	48·7	49·0	49·1	49·3	50·0	48·9	48·9	49·1	49·1	49·1	48·2	47·8
150	...	...	...	48·6	49·1	47·1	45·1	48·9	48·9	48·9	43·9	44·1
200	47·9	...	47·3	45·3	44·2	43·5	43·1	47·7	48·2	47·1	43·3	43·3
240	...	...	...	...	...	43·0	43·1(225)	45·5	47·8	...	...	43·1
250	...	...	...	...	...	43·0	43·1	...	...	...	43·1	43·1
260	...	...	...	...	...	...	...	...	...	43·9	...	...
300	47·2	48·9	46·4	43·2	43·0	...	...	...	...	...	...	...
400	46·9	...	45·3	42·8	42·8	...	...	...	...	...	...	...
500	43·2	...	43·9	...	42·8	...	...	...	...	...	...	...
550	...	...	43·0	42·7	...	...	...	...	...	...	...	...
700	...	...	...	42·6	42·5	...	...	...	...	...	...	...

Date	1903. Oct. 23.	1903. Oct. 23.	1903. Oct. 24.	1903. Oct. 24.	1903. Oct. 25.	1903. Oct. 26.	1903. Oct. 26.	1903. Oct. 27.	1903. Oct. 27.	1903. Oct. 27.	1903. Oct. 27.	1903. Oct. 27.
Time	10 a.m.	6 p.m.	10.30 a.m.	4.30 p.m.	10.30 a.m.	10 a.m.	4 p.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 0–1.	SW. 0–1.	Calm.	NE. 3–4.	SW. 1.	Calm.	Calm.	SW. 2.	SW. 1.	SW. 1.	SW. 0–½.	Dead calm.
Air Temp.	..	43·0	..	..	..	..	..	46·4	50·4	50·0	48·5	42·4
Depth. Feet.												
0	49·1	48·9	48·6	48·6	48·4	48·6	48·7	48·5	48·5	48·5	48·5	48·5
10	...	...	...	...	48·2	...	...	...	...	...	...	...
50	48·7	48·6	48·5	48·6	...	48·4	48·7	48·5	48·5	48·5	48·5	48·5
100	48·4	48·4	48·4	48·4	48·1	48·3	48·5	48·5	48·3	48·3	48·3	48·4
150	48·2	48·3	48·2	48·6	...	47·5	48·4	48·3	48·3	48·2	48·3	48·2
200	47·8	48·2	47·5	47·6	43·7	44·0	48·2	48·2	48·2	48·2	48·0	46·8
220	...	...	...	...	...	...	..	47·6	47·1	46·9	46·4	45·3
240	47·5	...	46·1(230)	46·9(230)	...	43·5	47·6	48·8	46·0	46·4	46·0	44·8
250	47·1	46 7	...	...	...	...	...	...	...	...	...	...

Date	1903. Oct. 27.	1903. Oct. 27.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 28.
Time	8 p.m.	10 p.m.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2.30 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 2.	NE. 3–4.	NE. 4–2.	NE. 2.	NE. 3–4.	NE. 3–4.	NE. 3–4.	NE. 5–6.	NE. 4.	Variable.	N. 0–½.	SW. 1.
Air Temp.	48·0	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	48·5	48·4	48·4	48·4	48·4	48·4	48·4	48·5	48·6	48·6	48·6	48·6
50	48·4	48·4	...	...	...	...	48·3	48·4	48·6	48·6	48·6	48·6
100	48·4	48·4	...	...	48·2	...	48·2	48·4	48·4	48·5	48·4	48·5
150	48·3	48·2	48·4	48·2	47·9	48·2	48·2	48·2	48·4	48·5	48·4	48·5
200	46·0	47·1	47·3	45·3	44·5	44·6	44·3	45·9	48·4	48·4	48·4	48·5
220	44·8	44·9	44·8	44·6	43·9	43·9	43·4(230)	43·9	44·5	47·9	48·2	48·6
240	44·5	...	...	...	...	...	...	...	...	...	...	...

Date	1903. Oct. 28.	1903. Oct. 28.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 29.
Time	10 p.m.	Midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	Calm.	Calm.	E. 2.	NE. 1.	NE. 1.	S. 0–½.	S. 1–3.	S. 0–1.	NE. 1–3.	SE. 1–3.	NE. 1–3.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	48·3	48·3	48·3	48·3	48·3	48·5	48·5	48·7	48·7	48·7	48·7	48·7
50	...	48·3	48·3	48·3	48·3	48·3	48·5	48·5	48·6	48·7	48·6	48·7
100	...	48·3	48·3	48·3	48·3	48·3	48·5	48·5	48·5	48·5	48·5	48·5
150	48·3	48·3	48·3	48·3	48·3	48·3	48·5	48·5	48·5	48·5	48·5	48·5
200	48·3	48·3	48·3	48·3	48·3	48·3	48·5	48·5	48·5	48·5	48·5	48·5
220	48·3	48·3	48·3	48·2	48·3	48·3	48·3	48·5	48·5	48·5	48·5	48·5

Date	1903. Oct. 29.	1903. Oct. 29.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.	1903. Oct. 30.
Time	10 p.m.	12 midnight.	2.30 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NNW. 0–2.	NE. 1.	SW. 1–2.	Calm.	SW. ½.	SW. 1.	SW. 0–2.	SW. 2.	SW. 2.	SW. 2.	SW. 1.	SW. 2.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	48·5	48·4	48·4	48·3	48·3	48·3	48·5	48·3	48·4	48·5	48·3	48·3
50	48·5	48·3	48·3	48·3	48·3	48·4	48·3	48·3	48·2	48·3	48·2	48·2
100	48·5	48·3	48·3	48·3	48·3	48·2	48·2	48·3	48·2	48·2	48·0	47·6
150	48·3	48·3	48·2	48·2	48·0	48·0	48·0	48·2	48·0	45·7	46·0	45·5
200	48·3	48·2	46·0	44·9	43·9	43·5	45·9	46·3	45·1	44·6	44·6	44·1
220	48·2	47·1	43·9	43·5	43·3	43·3	43·9	44·6	43·8	43·9	43·7	43·7

Date	1903. Oct. 30.	1903. Oct. 30.	1903 Oct. 31.	1903. Oct. 31.	1903. Oct. 31.	1903. Oct 31.	1903. Oct. 31.	1903. Oct. 31.	1903. Oct. 31.	1903. Oct. 31.	1903. Nov. 2.	1903. Nov. 2.
Time	10.30 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	10.30 a.m.	5 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 0–1.	SW. 1.	SW. 0–½.	Calm.	Calm.	Calm.	SW. 1.	SW. 1.	NW. 0–½.	Calm.	Calm.	SW. 0–1.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	48·2	48·2	48·1	48·0	48·2	48·2	48·3	48·2	48·3	48·3	48·2	48·2
50	48·2	48·0	48·0	48·0	48·0	48·1	48·2	48·2	48·2	48·0	48·2	48·2
100	48·0	47·8	47·8	47·8	47·6	47·8	47·6	47·6	47·5	47·3	48·2	48·0
150	46·0	45·1	44·1	43·9	43·9	43·9	44·0	44·1	44·8	46·4	48·0	46·5
200	43·5	43·3	43·3	43·2	43·2	43·4	43·5	43·5	43·6	44·6	46·7	45·9
220	43·3	43·2	43·2	43·0	43·1	43·2	43·1	43·1	43·3	43·5	46·4	45·3

Date	1903. Nov. 3.	1903. Nov. 3.	1903. Nov. 4.	1903. Nov. 4.	1903. Nov. 4.	1903. Nov. 5.	1903. Nov. 5.	1903. Nov. 5.	1903. Nov. 6.	1903. Nov. 6.	1903. Nov. 7.	1903. Nov. 7.
Time	10 a.m.	5 p.m.	10 a.m.	5 p.m.	9.30 p.m.	10.30 a.m.	4.30 p.m.	9 p.m.	9.30 a.m.	9.30 p.m.	10 a.m.	9 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	W. 1.	SW. 2.	S. 1.	SW. 0–1.	Calm.	SW. 1.	SW. 1.	Calm.	SW. ½.	Calm.	Calm.	SW. 0–½.
Air Temp.	..	..	..	..	..	..	..	42·5	38·0	33·0	39·0	44·0
Depth, Feet.												
0	48·2	47·5	47·6	47·3	47·5	47·9	47·8	47·6	47·6	47·2	47·5	47·2
5	...	...	...	...	...	...	...	...	47·7(4)	...	47·5	...
10	...	...	...	...	...	...	...	47·6	47·6	...	...	...
15	...	...	...	...	...	...	...	...	47·6	47·2	...	...
20	...	...	...	...	...	...	...	...	...	...	47·5	...
25	...	...	...	...	...	...	...	...	...	...	...	...
50	47·8	46·9	47·3	47·3	...	47·9	47·8	47·6	47·6	47·2	47·4	47·2
100	47·5	44·9	47·0	46·9	...	47·7	47·8	47·5	47·4	47·0	47·2	47·1
150	44·1	43·7	46·4	46·7	...	47·7	47·7	47·4	47·0	46·0	47·2	47·0
200	43·7	43·1	45·7	46·0	46·5	47·7	47·1	47·2	44·5	44·1	47·0	46·9
	43·7	43·0	45·1	45·7	...	47·7	46·7	46·2	44·1	43·9	47·0	46·6

Date	1903. Nov. 8.	1903. Nov. 8.	1903. Nov. 9.	1903. Nov. 9.	1903. Nov. 9.	1903. Nov. 10.	1903. Nov. 10.	1903. Nov. 11.	1903. Nov. 11.	1903. Nov. 12.	1903. Nov. 12.	1903. Nov. 12.
Time	10·30 a.m.	6 p.m.	10 a.m.	4 p.m.	9 p.m.	10 a.m.	9 p.m.	9 30 a.m.	9 p.m.	9.30 a.m.	1 p.m.	1 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Altsigh.	Abriachan	Yacht.
Wind	SW. 0–1.	SW. 2–3.	SW. 1.	SW. 2.	SW. 1.	SSW. 0–½.	Calm.	Calm.	SSW. 2–3.	SW. 1.	SW. 2–3.	SW. 1–2.
Air Temp.	50·0	..	44·0	..	42·0.	..	..	..	..	47·0.	47·0	..
Depth. Feet.												
0	47·4	47·2	47·1	46·9	46·5	47·0	46·6	46·9	46·8	48·0	48·8	46·8
50	47·4	47·1	47·0	46·8	46·4	46·8	46·6	...	...	...	...	46·7
100	47·2	47·0	46·9	46·6	46·0	46·7	46·5	...	...	47·8	48·5	46·5
150	47·2	47·0	46·6	45·9	44·3	46·5	46·4	...	...	47·3	...	45·9
200	47·0	46·5	45·0	44·0	43·4	46·3	46·2	46·7	46·5	45·4	48·5	45·3
220	46·8	46·2	44·6	43·8	43·3	46·2	45·3	...	46·5	...	...	44·6
250	...	...	...	...	...	...	..	...	...	44·6	48·0	...
300	...	...	...	...	...	...	...	...	...	43·9	46·0	...
350	...	...	...	...	...	...	...	...	...	...	43·5	...
400	...	...	...	...	...	...	...	...	...	43·4	43·5	...
500	...	...	...	...	...	...	...	...	...	43·1	43·3	...
700	...	...	...	..	...	...	...	...	...	43·1	...	...

Date	1903. Nov. 12.	1903 Nov. 12.	1903. Nov. 13.	1903. Nov. 13.	1903. Nov. 14.	1903. Nov. 14.	1903. Nov. 14.	1903. Nov. 15.	1903. Nov. 15.	1903. Nov. 15.	1903. Nov. 16.	1903. Nov. 16.
Time	2.30 p.m.	10 p.m.	3 p.m.	9 p.m.	9.30 a.m.	3 p.m.	9 p.m.	9 a.m.	3 p.m.	9 p.m.	9 a.m.	3 p.m.
Position	Lenie.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1–2.	Calm.	SW. 1–2.	SSW. 1–3.	Calm.	SW. ½.	Calm.	W. ½.	NW. ½.	Calm.	S. ¼.	NE. 1.
Air Temp.	47·0	..	..	..	50·0	43·0	42·0	42·0	46·0	39·0	39·0	..
Depth. Feet.												
0	48·2	46·8	46·5	46·6	46·5	46·5	46·5	46·2	46·7	46 7	46·9	46·9
50	...	46·6	46·4	46·6	46·5	46·5	46·3	46·4	46·8	46·8	47·0	46·9
100	48·2	46·1	46·1	46·4	46·4	46·4	46·2	46·2	46·8	46·8	47·0	46·9
150	...	44·7	45·1	46·3	46·2	45·9	46·0	46·2	46·7	46·7	46·9	46 9
200	48·1	43·4	43·8	46·0	46·0	45·9	45 8	46·2	46·7	46·7	46·9	46·8
220	...	43·2	43·7	45·7	45·8	45·8	45·5	46·2	46·7	46·7	46·9	46·8
250	47·8	...	...	...	...	...	...	...	46·5	46·5	46·9(244)	46·8(240)
255	...	...	...	...	45·0	45·2	45·2	45·1	...	...	...	...
275	45·5	...	...	...	...	...	...	...	...	...	...	...
300	44·6	...	...	...	...	...	...	...	...	...	...	...
400	43·5	...	...	...	...	...	...	...	...	...	...	...
500	43·1	...	...	...	...	...	...	...	...	...	...	...
500	43·1	...	...	...	...	...	...	...	...	...	...	...

Date	1903. Nov. 16.	1903. Nov. 16.	1903. Nov. 17.	1903. Nov. 17.	1903. Nov. 17.	1903. Nov. 17.	1903. Nov. 17.	1903. Nov. 18.	1903. Nov. 18.	1903. Nov. 18.	1903. Nov. 18.	1903. Nov. 18.
Time	6 p.m.	9 p.m.	9 a.m.	12 noon.	3 p.m.	6 p.m.	9 p.m.	9 a.m.	12 noon.	3 p.m.	6 p.m.	9 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	N. 0–½.	Calm.	S. 0–½.	NE. 2.	N. 0–1.	Calm.	..	SW. ½.	SW. 0–½.	SW. 0–1.	Calm.	SW. 0–¼.
Air Temp.	..	36·0	38·0	..	..	..	..	37·0	..	..	..	45·0
Depth. Feet.												
0	46·9	46·8	46·9	47·0	47·0	47·0	47·0	46·8	47·0	47·0	47·0	47·0
50	46·9	46·9	47·0	47·0	47·0	47·0	47·0	47·0	47·0	46·9	47·0	47·0
100	46·9	46·9	47·1	47·0	47·0	47·0	47·0	47·0	46·9	46·8	47·0	47·0
150	46·8	46·9	47·0	46·9	47·0	46·9	46·9	46·8	46·8	46·5	46·9	46·9
200	46·8	46·8	46·9	46·9	46·9	46·8	46·7	46·2	46·0	45·7	46·7	46·7
220	46·8	46·8	46·9	46·8	46·8	46·0	46·7	45·1	45·2	45·0	46·6	46·7
240	46·8	46·5(246)	45·6(255)	46·8(235)	46·1	45·1	46·3(246)	43·8(250)	43·7	43·5(250)	46·3(245)	46·6(255)

Date	1903. Nov. 19.	1903. Nov. 19.	1903. Nov. 19.	1903. Nov. 20.	1903. Nov. 20.	1903. Nov. 20.	1903. Nov. 21.	1903. Nov. 21.	1903. Nov. 21.	1903. Nov. 22.	1903. Nov. 22.	1903. Nov. 22.
Time	9.30 a.m.	3 p.m.	9 p.m.	10 a.m.	3 p.m.	9 p.m.	10 a.m.	3.30 p.m.	9 p.m.	11 a.m.	4 p.m.	9 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2.	SW. 0–½.	SW. 0–1.	SW. 0–1.	NW. 1.	SW. 0–1.	NW. 1.	NWW. 1.	Calm.	SW. 1.	SW. 2.	SW. 1.
Air Temp.	..	..	43·5	45·0	45·1	46·0	..	38·0	39·0	48·0	49·0	47·0
Depth. Feet.												
0	47·0	46·8	46·5	45·6	46·2	46·0	45·9	46·0	45·4	46·2	46·0	45·9
50	47·0	46·8	46·4	45·8	45·9	45·3	45·7	45·3	45·6	46·1	...	45·9
100	46·8	46·6	46·1	45·1	45·3	44·9	45·2	45·3	45·6	46·0	...	45·7
150	46·8	44·8	45·7	44·4	44·6	43·9	44·9	44·7	45·4	46·0	...	45·6
200	46·2	44·0	43·5	43·6	44·2	43·3	44·6	44·3	45·1	46·0	45·8	45·5
220	44·8	43·8	43·2	43·6	43·6	43·3	43·9	44·0	45·0	46·0	45·7	45·3
250	43·6	...	...	...	43·6	...	...	...	...	...	...	...
255	...	43·6	43·1(257)	...	...	...	...	...	...	45·9	...	...

Date	1903. Nov. 23.	1903. Nov. 23.	1903. Nov. 23.	1903. Nov. 24.	1903. Nov. 24.	1903. Nov. 24.	1903. Nov. 24.	1903. Nov. 24.	1903. Nov. 24.	1903. Nov. 25.	1903. Nov. 25.	1903. Nov. 25.
Time	9.30 a.m.	3 p.m.	9 p.m.	9.30 a.m.	9.30 a.m.	3 p.m.	3 p.m.	9 p.m.	9 p.m.	9.30 a.m.	9.30 a.m.	3 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.
Wind	S. 1–2.	S. 4–5.	SW. 0–½.	SW. 0–½.	Calm.	SW. 0–½.	SW. 3.	SW. 0–½.	SW. 4.	S. 1.	SW. 1.	SW. 0–1.
Air Temp.	47·0	..	47·0	37·0	38·5	38·0	41·0	37·0	..	36·0	38·5	36·0
Depth. Feet.												
0	45·8	45·2	45·0	44·3	47·3	44·1	47·2	44·1	47·0	44·6	47·0	44·7
50	45·8	45·1	44·8	44·4	...	44·2	...	44·2	...	44·8	...	45·0
100	45·7	45·0	44·0	44·2	...	44·2	...	44·2	...	44·8	...	44·9
150	45·3	44·4	43·4	43·8	...	43·9	...	44·2	...	44·7	...	44·8
200	45·0	43·9	43·1	43·1	...	43·8	...	44·0	...	44·4	...	44·8
220	44·5	43·4	43·1	43·1	...	43·8	...	43·4	...	44·4	...	44·8
250	44·0	...	...	...	...	...	...	...	...	44·2	47·0	...
255	...	43·2(265)	43·1	43·1	...	43·2(260)	...	42·9	...	...	...	44·5(260)
300	...	...	...	...	47·3	...	47·2	...	47·0	...	46·6	...
320	...	...	...	...	...	...	46·7	...	...	...	43·4(310)	...
330	...	...	...	...	43·7	...	44·0	...	...	...	...	...

Date	1903. Nov. 25.	1903. Nov. 25.	1903. Nov. 25.	1903. Nov. 26.	1903. Nov. 26.	1903. Nov. 26.	1903. Nov. 26.	1903. Nov. 26.	1903. Nov. 26.	1903. Nov. 27.	1903. Nov. 27.	1903. Nov. 27.
Time	3 p.m.	8 p.m.	9 p.m.	9.15 a.m.	9 a.m.	3 p.m.	3 p.m.	9 p.m.	9 p.m.	9.30 a.m.	9 a.m.	3 p.m.
Position	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.	Dores.	Yacht.
Wind	SW. 4.	S. 0–½.	Calm.	W. wind 0–1.	Calm.	W. 0–½.	Calm.	Calm.	Calm.	SW. 0–½.	Calm.	Calm.
Air Temp.	38·5	..	..	36·0	37·0	35·0	36·0	32·8	33·4	33·0	36·0	36·0
Depth. Feet.												
0	47·0	44·7	47·0	45·0	46·9	45·0	46·9	45·0	46·8	45·5	46·7	45·4
50	...	44·9	...	45·1	47·0	45·0	...	...	...	45·7	...	...
100	...	44·9	...	45·0	...	45·0	...	45·0	...	45·3	...	45·3
150	...	44·8	...	45·0	...	45·0	...	...	46·8	45·3	46·8	...
200	...	44·8	47·0	45·0	47·0	45·0	46·9	45·0	46·0	45·3	46·3	45·4
220	...	44·8	46·8(240)	45·0	...	45·0	...	...	...	45·3	...	...
250	47·0	...	46·7	44·9	45·0	45·0	45·6	45·0	43·8	..	44·6	45·3
260	...	44·6	...	...	...	...	...	...	...	45·2	...	...
300	43·5	...	43·3	...	43·3	...	43·3	...	43·1	...	43·3	...
310	43·2	...	...	...	...	...	...	...	...	...	...	...
330	43·2	...	43·0	...	43·2	...	43·2	...	43·1	...	43·2	...

Date	1903. Nov. 27.	1903. Nov. 27.	1903. Nov. 27.	1903. Nov. 28.	1903. Nov. 28.	1903. Nov. 28.	1903. Nov. 28.	1903. Nov. 28.	1903. Nov. 29.	1903. Nov. 29.	1903. Nov. 29.	1903. Nov. 29.
Time	3 p.m.	9 p.m.	9 p.m.	9.30 a.m.	9 a.m.	3 p.m.	9 p.m.	9 p.m.	9.15 a.m.	3.15 p.m.	3 p.m.	9 p.m.
Position	Dores.	Yacht.	Dores.	Yacht.	Dores.	Dores.	Yacht.	Dores.	Yacht.	Yacht.	Dores	Yacht.
Wind	0–½.	NE. 1.	Calm.	NE. 3.	NE. 1–2.	NNE. 3.	NE. 2–3.	NE. 1.	Calm.	SW. 0–½.	N. 0–1.	Calm.
Air Temp.	36·0	36·0	..	39·0	..	..	39·0	36·5	28·0	29·0	37·5	28·0
Depth. Feet.												
0	46·8	45·6	46·7	45·5	46·7	46·6	45·8	46·3	45·4	45·5	46·0	45·4
10	...	...	...	...	...	...	...	...	45·8	...	...	...
50	...	...	...	...	...	...	...	...	...	45·8	...	45·7
100	...	45·4	...	...	46·7	46·6	...	46·3	45·7	...	45·7	
150	46·8	...	46·7	...	46·4	46·1	...	45·2	...	...	45·4	45·6
200	46·5	45·4	46·5	...	45·6	44·3	...	44·0	45·4	45·4	45·0	45·4
220	...	...	...	45·4	...	...	45·5	...	45·4(235)	45·4(245)	...	...
250	44·7	45·4(240)	45·0	...	43·8	43·4	...	43·5	...	...	44·9	45·3
300	43·5	...	43·4	...	43·4	...	...	43·2	...	...	44·4	...
330	43·3	...	43·2	...	43·3	...	...	43·1	...	...	44·1	...

Date	1903. Nov. 30.	1903. Nov. 30.	1903. Nov. 30.	1903. Nov. 30.	1903. Nov. 30.	1903. Dec. 1.	1903. Dec. 2.	1903. Dec. 3.	1903. Dec. 4.	1903. Dec. 4.	1903. Dec. 5.	1903. Dec. 6.
Time	9.30 a.m.	9 a.m.	3 p.m.	4 p.m.	9 p.m.	12.30 p.m.	11.30 a.m.	10.30 a.m.	9.30 a.m.	3 p.m.	3 p.m.	11 a.m.
Position	Yacht.	Dores.	Yacht.	Glendoe.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	S. 0–½.	SW. 1.	Calm.	Calm.	Calm.	Calm.	Calm.	SW. 2.	SW. 1–2.	SW. 1.	SW. 0–½.	SW. 0–½.
Air Temp.	24·5	..	29·0	..	..	29·0	34·0	..	34·0	35·8	..	36·5
Depth. Feet.												
0	45·0	45·8	45·0	...	45·1	45·3	45·3	44·2	44·0	43·6	44·1	44·6
10	45·5	...	...	.	...	...	...	...	...	...	...	...
50	45·6	...	45·6	...	45·2	45·3	45·4	43·8	44·0	43·8	43·6	44·6
100	...	45·7	...	...	...	...	...	43·7	43·9	43·7	43·5	...
150	...	45·5	...	...	...	...	...	...	...	...	...	. .
200	45·6	45·3	45·2	...	...	45·1	...	43·7	43·6	43·3	43·3	44·4
240	45·4(220)	...	45·2	...	44·6	45·0	45·0(235)	43·6	43·5	43·3	...	...
250	...	45·0	...	...	...	...	...	...	...	...	...	44·4
300	45·4*	44·9	...	44·2	...	...	...	...	...	...	...	...
330	45·1*	44·3	...	43·5(320)	...	...	...	...	...	...	...	...

* These two observations were made a little to the north-east of the Yacht.

Date	1903. Dec. 7.	1903. Dec. 7.	1903. Dec. 8.	1903. Dec. 9.	1903. Dec. 10.	1903. Dec. 11.	1903. Dec. 12.	1903. Dec. 13.	1903. Dec. 14.	1903. Dec. 15.	1903. Dec. 16.	1903. Dec. 17.
Time	10.30 a.m.	3 p.m.	10.30 a.m.	10.30 a.m.	10.15 a.m.	10.15 a.m.	10.10 a.m.	3.30 p.m.	10.15 a.m.	12.45 p.m.	10 a.m.	10.30 a.m.
Position.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	..	SW. 1.	SE. 0-½.	SE. 0-1.	Calm.	NW. 0-½.	NW. 0-½.	NE. 3.	Calm.	Calm.	S. 0-1.	S. 3-4.
Air Temp.	..	40·0	43·0	41·0	33·0	37·0	41·9	..	40·8	42·3	40·0	42·0
Depth. Feet.												
0	44·4	44·4	44·5	44·5	44·5	44·4	44·3	44·3	44·3	44·3	44·3	44·1
50	44·4	44·4	44·2	44·5	44·5	44·4	44·4	...	44·3	44·3	44·3	44·1
100	44·4	44·2	44·0	44·3	44·3	44·4	44·4	...	44·3	44·3	44·3	44·1
200	44·2	44·2	43·9	44·1	44·1	44·2	44·3	...	44·3	44·3	44·3	44·1
240	44·1	44·1	43·9	44·0	44·1	44·2	...	44·2(230)	44·3	44·3	44·1	44·0
250	...	..	...	...	...	...	44·2	...	...	...	...	...

Date	1903. Dec. 18.	1903. Dec. 19.	1903. Dec. 20.	1903. Dec. 21.	1903. Dec. 21.	1903. Dec. 22.	1903. Dec. 23.	1903. Dec. 24.	1903. Dec. 25.	1903. Dec. 26.	1903. Dec. 26.	1903. Dec. 27.
Time	2.30 p.m.	9 a.m.	3·30 p.m.	8.30 a.m.	4.30 p.m.	8.10 a.m.	8 a.m.	3.45 p.m.	10 a.m.	10.30 a.m.	2.30 p.m.	5 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 2.	NE. 3-4.	Calm.	SSW. 4-5.	SSW. 5-6.	SW. 1.	SW. 1.	Calm.	Calm.	SW. ½.	NE. 1-2.	E. 1.
Air Temp.	..	36·0	42·0	..	..	47·0	44·0	38·5	33·5	25·0	26·0	37·5
Depth. Feet.												
0	44·1	44·0	44·0	44·0	44·0	43·7	43·3	43·2	43·5	43·7	43·7	43·6
5	...	...	...	...	...	...	...	...	...	...	43·8	...
10	...	...	...	...	...	...	...	...	...	...	43·8	...
50	...	44·0	...	44·0	...	43·6	43·3	...	...	...	...	...
100	44·0	44·0	...	44·0	...	43·2	43·2	...	43·5	43·8	43·7	...
200	44·0	44·0	...	44·0	...	43·1	43·2	...	...	43·7	...	...
230	44·0	44·0	...	...	...	...	...	...	...	...	...	43·6
240	...	...	43·9	...	43·8	...	...	...	...	43·7	...	...
250	...	...	...	43·9	...	43·1	43·0	42·9	43·1	...	...	...

Date	1903. Dec. 28.	1903. Dec. 29.	1903. Dec. 29.	1903. Dec. 30.	1903. Dec. 30.	1903. Dec. 30.	1903. Dec. 30.	1903. Dec. 30.	1903. Dec. 30.	1903. Dec. 31.	1903. Dec. 31.	1903. Dec. 31.
Time	8 a.m.	8 a.m.	11.30 p.m.	8.5 a.m.	3 p.m.	3 p.m.	3 p.m.	3 p.m.	3 p.m.	6 a.m.	3 p.m.	3 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	At Mouth of Canal.	10 Strokes into Loch.	10 Strokes further.	In Canal, at Light-house.	Further in Canal, opposite Monastery Tower.	Yacht.	Opposite Tower of Monastery	At Light-house.
Wind	Calm.	SW. 1.	Ripple.	SW. 0-½.	..	..	..	..	..	E. 0-3.	..	..
Air Temp.	36·0	34·0	23·5	20·0	..	..	..	..	..	40·0	..	..
Depth. Feet.												
0	43·7	43·7	43·4	43·1	43·2	43·4	43·4	37·7	36·9	43·4	36·9	37·0
10	...	...	...	43·5	42·9	43·3	...	...	...	...	...	38·3
15	...	...	...	...	38·9(18ft.)	41·8(18ft.)	43·5(20ft.)	38·3	38·7	...	37·6	39·0
25	...	...	43·5+	43·6	...	...	...	...	...	...	...	...
30	...	...	...	43·6	...	...	...	...	...	...	...	...
45	...	...	...	...	...	...	40·0	...	...	...	...	...
50	...	43·7	...	43 6	...	...	...	...	...	43·4	...	...
100	43·7	43·7	...	43·6	...	...	...	...	...	43·3	...	...
200	43·7	43·6	..	43·5	...	...	...	...	...	43·1	..	...
230	43·5	...	...	43·3	...	...	...	...	...	43·1	...	...
240	...	43·2	...	...	...	...	...	...	...	...	..	...

Date	1904. Jan. 1.	1904. Jan. 2.	1904. Jan. 4.	1904. Jan. 5.	1904. Jan. 6.	1904. Jan. 7.	1904. Jan. 8.	1904. Jan. 8.	1904. Jan. 9.	1904. Jan. 10.	1904. Jan. 11.	1904. Jan. 12.
Time	10.30 a.m.	7.15 a.m.	8 a.m.	8 a.m.	8 a.m.	8 a.m.	8.30 a.m.	2.30 p.m.	9.45 a.m.	4 p.m.	11.50 a.m.	9.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Variable.	SE. 0–1.	SE. 0–1.	SW. 1.	SW. 0–1.	SW. 3.	SW. 1.	SW. 0–¼.	SW. ½.	SW. ¼–1.	W. ½–1.	W. ½–½.
Air Temp.	42·0	40·0	..	30·0	41·0	40·0	38·0	38·0	37·0	34·0	35·0	36·5
Depth. Feet.												
0	43·3	43·3	43·1	43·0	43·0	43·1	43·1	43·1	43·0	42·8	43·0	42·9
50	...	...	...	...	...	...	...	...	...	43·1	...	...
100	...	...	...	...	...	...	...	43·2	43·0	...	43·0	42·9
200	...	...	...	...	...	...	...	42·9	42·9	...	42·5	...
230	...	43·1	43·0	43·0	43·0	43·0	42·7	...	...	...	...	...
250	43·2	...	...	...	...	...	...	...	42·6(255)	...	42·1	...
260	...	...	...	...	...	...	...	42·2	...	42·1	...	42·3

Date	1904. Jan. 13.	1904. Jan. 14.	1904. Jan. 15.	1904. Jan 16.	1904. Jan. 17.	1904. Jan. 18.	1904. Jan. 19.	1904. Jan. 20.	1904. Jan. 21.	1904. Jan. 22.	1904. Jan. 23.	1904. Jan. 25.
Time	10.15 a.m.	10.20 a.m.	10.15 a.m.	10.30 a.m.	..	10 a.m.	9.50 a.m.	10.5 a.m.	10.5 a.m.	10.10 a.m.	10 a.m.	10.5 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 0–½.	SW. ½.	SW. ½.	Calm.	..	SW. ½–1.	Calm.	SW. 2.	SW. ¼.	SW. 2.	SW. 1.	SW. 0–½.
Air Temp.	41·5	41·0	35·5	34·2	40·0	47·5	47·2	44·5	39·0	42·1	44·0	39·0
Depth. Feet.												
0	43·0	42·5	42·7	42·8	42·6	42·8	42·7	42·2	42·1	42·3	42·2	42·3
50	...	42·5	...	...	...	...	...	...	...	...	...	...
100	42·8	42·2	42·2	42·3	...	...	...	...	...	...	42·2	...
250	...	42·0	...	42·0	...	...	42·0	...	...	...	...	...
260	42·3	...	42·1	...	42·0	42·0	...	41·9	41·8	41·9	41·9	42·0

Date	1904. Jan. 26.	1904. Jan. 27.	1904. Jan. 29.	1904. Feb. 2.	1904. Feb. 3.	1904. Feb. 4.	1904. Feb. 5.	1904. Feb. 6.	1904. Feb. 8.	1904. Feb. 9.	1904. Feb. 10.	1904. Feb. 11.
Time	10.55 a.m.	10.30 a.m.	10.30 a.m.	10 a.m.	10. a.m.	10.5 a.m.	10.15 a.m.	10.15 a.m.	10.10 a.m.	10.15 a.m.	10.20 a.m.	11.5 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	W. 1.	..	..	NE.	..	NE. 2.	NE. 1.	NE. 2–3.	NE. 3.	Calm.	SW. 0–¼.	Calm.
Air Temp.	44·0	45·0	39·0	40·0	39·0	36·5	35·0	36·0	36·0	34·7	31·5	42
Depth. Feet.												
0	42·3	42·2	41·9	42·1	42·2	42·3	42·2	42·2	42·1	42·1	42·0	42·0
100	...	...	...	...	....	...	42·2	...	...	...	...	...
200	...	...	...	42·0	...	...	...	...	...	...	...	...
235	...	...	...	...	42·0	42·0	42·1	41·6	42·0	...	...	41·9(240)
250	...	42·0	...	...	...	...	...	...	...	42·0	41·8	...
260	42 0	...	41·6	...	...	...	...	...	...	...	...	...

Date	1904. Feb. 12.	1904. Feb. 13.	1904. Feb. 15.	1904. Feb. 16.	1904. Feb. 17.	1904. Feb. 18.	1904. Feb. 19.	1904. Feb. 20.	1904. Feb. 22.	1904. Feb. 23.	1904. Feb. 24.	1904. Feb. 25.
Time	10.5 a.m.	10.30 a.m.	3 p.m.	10.30 a.m.	10.30 a.m.	11.45 a.m.	10.30 a.m.	10.20 a.m.	10.35 a.m.	10 a.m.	10.30 a.m.	10.15 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	SW. 0–¼.	SW. 1–2.	SW. 3.	Calm.	N. ½–1.	W. 1.	SW. 2.	SW. 0–¼.	SW. 3–4.	SW. 2.	SW. 2.
Air Temp.	42·0	42·5	35·0	38·0	37·0	38·0	34·0	42·5	40·0	42·0	40·0	41·0
Depth. Feet.												
0	42·0	42·0	42·0	41·8	41·8	41·8	41·5	41·0	41·6	41·3	41·1	41·4
240	...	...	...	...	...	41·3	...	...	41·1	...	...	...
250	41·9(255)	...	...	41·0(255)	41·4	...	41·3	41·0	...	40·6(255)	...	...
260	...	41·8	41·2	...	...	...	...	...	...	...	41·0	41·0

Date	1904. Feb. 26.	1904. Feb. 27.	1904. Feb. 29.	1904. Mar. 2.	1904. Mar. 3.	1904. Mar. 4.	1904. Mar. 5.	1904. Mar. 7.	1904. Mar. 8.	1904. Mar. 10.	1904. Mar. 11.	1904. Mar. 12.
Time	10.30 a.m.	10.15 a.m.	2.30 p.m.	10.15 a.m.	3.30 p.m.	10.30 a.m.	12.5 p.m.	5 p.m.	3 p.m.	11.5 a.m.	10,35 a.m.	11 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 0–¼.	SW. 0–¼.	SW. 1.	Calm.	S. ½–3.	S. ½.	NE. 2.	NE. 1.	NE. 1.	Calm.	SW. 1–2.	SW. 1.
Air Temp.	36·0	42·0	33·0	31·0	40·5	38·7	39·2	39·0	38·5	40·5	45·5	46·0
Depth. Feet.												
0	41·7	41·9	41·1	41·4	41·3	41·4	41·4	41·3	41·3	42·5	41·6	41·6
240	...	...	...	...	...	...	41·2	...	...	41·0	...	...
250	...	41·0	...	41·0	41·1	41·2	...	...	...	...	41·2	41·2
260	41·0	...	41·1	...	...	...	...	...	...	...	...	...

Date	1904. Mar. 12.	1904. Mar. 14.	1904. Mar. 15.	1904. Mar. 16.	1904. Mar. 17.	1904. Mar. 18.	1904. Mar. 19.	1904. Mar. 21.	1904. Mar. 22.	1904. Mar. 23.	1904. Mar. 24.	1904. Mar. 25.
Time	11 a.m.	11.30 a.m.	1.15 p.m.	10.30 a.m.	4.30 p.m.	2.40 p.m.	..	4 p.m.	3.30 p.m.	11.15 a.m.	11 a.m.	10.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	Variable 0–1.	SW. ¼–1.	SW. 1.	SW. 2.	SW. 3–4.	SSW. 2.	SW. 2.	SW. 2.	NE. 0–¼.	Calm.	Calm.
Air Temp.	46·0	36·0	39·0	44·5	44·5	44·0	..	42·0	43·5	53·0	49·5	45·0
Depth. Feet.												
0	41·6	41·4	41·7	41·3	41·2	41·2	41·3	41·1	41·1	42·7	42·3	42·1
250	41·2	41·0	41·0	...	...	...	...	...	...	41·0	41·0	41·0
260	...	...	...	40·9	40·8	40·5	41·0	41·0	41·0	...	...	...

Date	1904. Mar. 26.	1904. Mar. 28.	1904. Mar. 29.	1904. Mar. 30.	1904. Mar. 31.	1904. Apr. 1.	1904. Apr. 2.	1904. Apr. 4.	1904. Apr. 5.	1904. Apr. 6.	1904. Apr. 11.	1904. Apr. 12.
Time	11 a.m.	12 noon.	10.35 a.m.	11.45 a.m.	10.30 a.m.	3.45 p.m.	4.30 p.m.	11 a.m.	10.15 a.m.	3.30 p.m.	11.30 a.m.	10.30 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 1.	SSW. 4.	SW. 1.	SW. ½.	SW. 1–2.	SW. 1–4.	SW. 2–4.	SW. 2.	SW. 2.	SW. 2.	SW. ½.	SW. ½.
Air Temp.	42·0	46·0	39·5	38·0	44·5	39·0	38·5	43·0	44·5	43·0	48·0	47·0
Depth. Feet.												
0	41·3	41·4	41·2	41·6	41·3	41·3	41·3	41·1	41·0	41·0	41·3	41·3
250	41·0	...	...	...	41·0	...	...	...	...	...	...	...
260	...	41·0	40·9	41·0	...	41·2	41·1	41·0	41·0	41·0	41·0	41·0

Date	1904. Apr. 13.	1904. Apr. 14.	1904. Apr. 15.	1904. Apr. 16.	1904. Apr. 18.	1904. Apr. 20.	1904. Apr. 21.	1904. Apr. 22.	1904. Apr. 23.	1904. Apr. 25.	1904. Apr. 26.	1904. Apr. 27.
Time	12 noon.	11 a.m.	1.30 p.m.	12 noon.	3 p.m.	10 a.m.	10.15 a.m.	10 a.m.	12 noon.	5 p.m.	4.45 p.m.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Variable 1–3.	NNE. ½.	SW. 1.	W. 1.	SW. 1.	..	SW. 1.	SW. ½–1.	SW. 1.	W. 1.	SW. 1.	SW. 1–2.
Air Temp.	47·0	49·5	52·0	49·5	53·5	..	47·9	48·0	51·0	42·0	42·5	..
Depth. Feet.												
0	41·3	41·5	41·6	41·5	41·6	41·6	41·6	41·9	41·5	41·7	41·2	41·4
10	...	...	...	...	...	...	...	...	41·4	41·6	41·2	41·4
50	...	...	...	...	...	...	...	...	41·2	40·9	41·1	41·4
100	...	..	...	...	...	...	...	...	41·2	40·9	40·9	41·1
150	...	...	...	...	...	...	...	...	41·1	...	...	...
200	...	...	...	...	...	...	...	...	41·1	...	...	...
250	41·0	41·0	...	41·0	...	40·8	...	...	41·1	...	...	...
260	...	...	41·2	...	40·9	...	40·7	41·1	41·1	40·8	40·9	40·9

Date	1904. April 29.	1904. April 30.	1904. May 2.	1904. May 3.	1904. May 4.	1904. May 5.	1904. May 5.	1904. May 5.	1904. May 6.	1904. May 6.	1904. May 7.	1904. May 9.
Time	1 p.m.	3 p.m.	10.30 a.m.	12 noon.	10.30 a.m.	10 a.m.	11 a.m.	6 p.m.	10.30 a.m.	8 p.m.	5 p.m.	2.30 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Near Inver-farigaig Pier.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	SW. 3.	SW. 2.	SW. 1-2.	Calm.	NE. 0–1.	..	S. 1.	NE. 3–4.	NE. 2.	NE. 3.	NE. 3.
Air Temp.	51·0	45·0	35·0	51·0	52·0	..	..	..	..	..	..	..
Depth. Feet.												
0	41·5	41·6	41·6	41·6	42·9	43·5	43·6	43·1	42·9	42·7	42·6	42·8
5	...	...	...	...	...	...	43·4	...	...	...	...	...
10	41·5	41·5	41·6	41·6	42·2	...	43·0	...	...	...	42·6	42·8
25	...	...	...	...	...	...	43·0	...	...	...	...	...
50	41·3	41·4	41·6	41·6	41·7	43·0	42·9	...	...	...	42·6	42·8
75	...	...	...	...	...	...	42·7	...	...	...	...	...
100	40·9	40·9	41·5	41·6	41·6	42·8	42·4	...	42·8	...	42·6	42·7
110	...	...	...	...	...	...	42·4	...	...	...	...	...
125	...	...	...	...	...	42·5	...	...	...	...	...	...
150	...	...	...	...	...	42·0	...	...	...	...	...	...
200	...	...	...	...	...	42·0	...	...	42·8	42·6	...	42·6
244	...	...	...	...	41·3	...	...	42·3	...	...	42·6(230)	...
260	40·9	40·9	41·1	41·5	...	...	...	...	...	...	...	...
300	...	...	...	...	...	41·8	...	...	...	...	...	...
500	...	...	...	...	...	41·5	...	...	...	...	...	...
700	...	...	...	...	...	41·3	...	...	...	...	...	...

DATE	1904. May 10.	1904. May 10.	1904. May 10.	1904. May 10.	1904. May 11.	1904. May 11.	1904. May 11.	1904. May 11.	1904. May 11.	1904. May 12.	1904. May 13.	1904. May 14.
TIME	10 a.m.	11 a.m.	11.30 a.m.	12 noon.	10.15 a.m.	11 30 a.m.	12.30 p.m.	2 p.m.	3 p.m.	2.30 p.m.	2.30 p.m.	10 a.m.
POSITION	Yacht.	Inver-farigaig.	Inver-farigaig, West Shore.	Inver-farigaig, East Shore.	Yacht.	Inver-farigaig, near Pier.	Inver-farigaig, West Shore.	Foyers.	Inver-farigaig, near Pier.	Yacht.	Yacht.	Inver-farigaig.
WIND	NE. 3.	NE. 2.	NE. 1.	..	NE. ½.	NE. 0–½.	..	Calm.	SW. 1–2.	SW. 1.	SW. 1–2.	SW. 4.
AIR TEMP.	..	43·9	..	..	..	46·6	..	..	..	..	..	..
DEPTH. FEET.												
0	42·7	42·0	42·1	42·0	43·0	43·3	43·0	43·5	43·0	42·8	42·6	42·7
2	...	...	...	...	...	42·8	...	...	42·5	...	...	...
5	...	...	..	...	...	42·4	42·7	43·1	42·4	...	...	...
10	42·7	..	...	...	43·0	42·3	42·5	43·0	...	42·8	42·5	...
25	...	...	...	...	...	42·3	42·3	42·6	...	...	...	...
50	42·7	...	...	...	42·8	42·2	...	42·4	...	42·7	42·4	42·5
75	...	...	...	...	...	...	42·2	...	...	...	...	...
100	42·6	...	...	42·0	42·6	42·1	...	42·3	...	42·6	42·3	42·3
200	42·6	42·0	42·1	42·0	42·6	42·0	...	...	...	42·4	...	...
253	...	...	...	...	...	...	...	...	...	...	41·9	...
300	...	42·0	...	...	...	...	...	42·1	...	...	...	42·2
500	...	41·9	...	...	...	...	...	41·8	...	...	...	42·0
600	...	...	...	...	...	...	...	...	...	...	...	41·7
650	...	...	...	...	...	...	...	...	...	...	...	41·5
700	...	41·9	...	...	...	...	...	...	...	...	...	41·3(690)

DATE	1904. May 14.	1904. May 14.	1904. May 16.	1904. May 17.	1904. May 18.	1904. May 18.	1904. May 18.	1904. May 19.	1904. May 19.	1904. May 19.	1904. May 20.	1904. May 21.
TIME	11 a.m.	11 a.m.	3.45 p.m.	4.30 p.m.	10 a.m.	11 a.m.	12 noon.	10.15 a.m.	11 a.m.	12 noon.	10.30 a.m.	10 a.m.
POSITION	Inver-farigaig, near Pier.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Inver-farigaig, West Shore.	Yacht.	Inver-farigaig, near Pier.	Inver-farigaig, Centre of Loch.	Yacht.	Yacht.
WIND	SW. 2–3.	SW. 2.	SSW. 4.	SW. 2–4.	SW. 2–3.	SW. 2–3.	..	WNW. 0–2.	W. 0–1.	..	W. ½.	NE. 1.
AIR TEMP.	..	50·0	63·0	..	50·5	46·0	..	48·0	..	..	58·0	45·0
DEPTH. FEET.												
0	43·1	42·2	42·4	41·9	42·4	42·7	42·4	42·7	42·9	43·0	42·8	44·8
10	...	42·2	42·4	...	42·4	...	...	42·6	...	...	42·8	...
50	43·0	42·1	42·1	...	42·2	42·5	...	42·4	42·8	42·6	42·7	42·7
100	43·0	41·9	41·9	...	42·4	42·6	...	42·0	42·6	42·5	42·6	41·9
150	...	...	...	...	...	42·5	...	...	42·5	...	...	41·9
200	42·9	...	...	...	...	42·5	42·3	...	...	42·4	42·4	41·9
250	...	...	...	...	...	...	...	41·7	...	...	...	...
260	...	41·6	41·6	...	41·6	...	...	...	...	...	...	...
400	...	...	...	...	...	42·2	42·0	...	...	42·3	...	...
600	...	...	...	...	...	41·8	41·8	...	...	41·7	...	...
625	...	...	...	...	...	41·7	...	...	...	...	...	...

Date	1904. May 21.	1904. May 21.	1904. May 23.	1904. May 23.	1904. May 24.	1904. May 24.	1904. May 24.	1904. May 24.	1904. May 24.	1904. May 24.	1904. May 24.	1904. May 25.
Time	10 a.m.	10.30 a.m.	11 a.m.	5.45 p.m.	10.30 a.m.	10.45 a.m.	11.45 a.m.	1.45 p.m.	2.30 p.m.	3.30 p.m.	8 p.m.	10 a.m.
Position	Inver-farigaig, near Pier.	Inver-farigaig, Centre of Loch.	Yacht.	Yacht.	Inver-farigaig, near Pier.	Yacht.	Foyers.	Inver-farigaig.	Inver-farigaig, West Shore.	Inver-farigaig, near Pier.	Yacht.	Yacht.
Wind	Calm.	..	SW. 1–2.	SW. ½.	NE. 0–½.	Calm.	SW. 0–2.	..	..	..	Calm.	W. 0–½.
Air Temp.	50·5	..	..	..	..	57·0	..	51·0	..	..	50·0	51·0
Depth. Feet.												
0	45·0	45·0	43·4	42·6	44·9	47·6	45·0	44·1	43·8	45·0	43·1	46·5
5	43·6	44·8	...	42·6	...	45·1	44·9	44·0	...	...	...	45·5
10	43·3	44·7	...	...	...	...	...	...	...	...	...	...
25	...	44·6	...	...	...	...	44·5	43·8	42·8	...	...	...
45	...	43·7	...	...	...	...	...	...	...	...	...	...
50	43·1	43·6	42·8	42·6	44·3	42·6	44·4	43·8	42·6	44·5	42·4	42·4
75	...	...	...	...	43·9	...	...	43·3	...	...	...	...
100	42·6	43·0	42·6	42·6	43·4	42·4	43·4	43·0	42·5	44·4	42·4	42·4
150	...	...	42·6	42·0	43·1	42·3	...	42·7	...	...	...	42·3
200	42·4	42·4	42·6	42·5	42·6	42·3	...	42·3	42·4	...	42·3	42·2
250	...	...	...	...	...	...	42·3	...	...	...	...	...
260	...	...	42·5	...	42·3(270)	...	...	...	...	...	...	...
400	...	...	...	...	...	...	42·1	42·1	...	...	...	...
500	...	42·2	...	...	...	...	...	...	...	...	...	...
600	...	...	...	...	...	...	...	41·8	...	...	...	...
650	...	41·9	...	...	...	...	...	...	...	...	...	...

Date	1904. May 25.	1904. May 25.	1904. May 25.	1904. May 25.	1904. May 26.	1904. May 26.	1904. May 26.	1904. May 26.	1904. May 26.	1904. May 26.	1904. May 26.	1904. May 26.
Time	11 a.m.	12 noon.	3 p.m.	6 p.m.	8 a.m.	8.30 a.m.	10.15 a.m.	11 a.m.	12 noon.	2.30 p.m.	3.30 p.m.	4 p.m.
Position	Inver-farigaig, West Shore.	Foyers.	Inver-farigaig.	Yacht.	Inver-farigaig.	Foyers.	Yacht.	Inver-morriston, North.	Yacht.	Temple.	Abriachan	Yacht.
Wind	Calm.	SW. 1.	Calm.	SW. ¼.	Calm.	Calm.	Calm.	NE. 0–1.	NE. ½.	SW. 1.	NE. 0–1.	SW. 4–5–0.
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	45·4	46·2	46·5	43·3	45·6	45·8	46·2	46·2	47·6	46·4	46·8	45·4
2	44·0	45·8	...	...	...	...	...	...	...	...	...	...
5	43·7	45·3	44·3	...	...	...	46·8	...	...	...	...	...
10	43·1	43·8	...	...	45·0	...	...	43·8	...	...	...	43·1
25	...	...	44·0	...	44·8	43·9	42·5	...	...	44·2	44·8	...
40	43·0	...	...	...	...	...	...	...	...	...	...	...
50	...	43·7	43·6	42·4	43·7	43·5	42·3	43·2	42·4	43·8	44·5	42·3
100	43·0	43·0	43·0	42·3	43·5	43·0	42·3	43·0	42·3	43·2	43·2	42·2
150	42·8	...	43·0	...	43·1	42·9	42·3	42·6	42·3	43·0	...	...
200	...	42·6	...	42·3	...	...	42·2	...	42·3	...	43·0	42·1
250	...	...	42·5	...	42·5	42·5	42·2	42·3	...	42·7	...	...
300	...	42·3	...	...	...	...	...	...	...	...	...	...
350	...	...	...	...	...	...	...	...	...	...	42·0	...
400	...	...	42·2	...	42·2	...	...	42·2	...	42·2	...	...
500	...	42·0	...	...	...	42·1	...	...	...	...	...	...
600	...	...	41·9	...	41·8	...	...	42·0	...	41·9	...	...

Date	1904. May 27.	1904. May 27.	1904. May 27.	1904. May 27.	1904. May 27.	1904. May 28.	1904. May 28.	1904. May 30.	1904. May 30.	1904. May 30.	1904. May 30.	1904. May 30.
Time	10.15 a.m.	11 a.m.	11.30 a.m.	12 noon.	7.30 p.m.	10.15 a.m.	3.45 p.m.	11.15 a.m.	3.45 p.m.	10 p.m.	11 p.m.	12 midnight.
Position	Yacht.	Inverfarigaig West Shore.	Inverfarigaig.	Inverfarigaig, near Pier.	Yacht.	Yacht.	Yacht.	Yacht.	Railway Pier, opposite.	Yacht.	Yacht.	Yacht.
Wind	NE. ½.	NE. 1.	..	..	NE. 3–4.	NE. 3.	NE. 3.	NE. 4.	..	Calm.	SSE. 0–1.	Variable 0–2.
Air Temp.	50·0	53·2	..	..	..	..	..	..	..	..	55·0	54·4
Depth. Feet.												
0	45·6	46·0	47·3	47·0	45·3	44·4	47·6	47·6	46·8	47·3	47·0	47·0
5	...	...	...	...	...	44·4	46·6	47·5	46·5	47·3	47·0	47·0
10	...	44·8	46·6	46·4	...	...	...	...	...	47·0	46·9	46·9
25	...	...	45·0	45·6	...	...	...	...	...	46·7	46·5	...
35	...	...	...	...	...	...	...	...	...	...	...	46·4
50	42·3	44·1	44·0	45·0	43·6	44·4	44·4	45·8	46·4	46·3	46·4	46·3
75	...	44·0	...	...	...	...	...	...	...	...	...	...
100	42·3	43·7	43·1	43·0	43·6	44·4	44·4	45·6	46·1	45·7	45·8	45·5
150	42·2	...	42·9	42·6	...	44·4	44·4	44·6	45·5	45·2	45·1	44·9
200	42·2	...	...	...	42·3	44·3	44·4	44·4	44·6	44·5	44·0	43·9
250	...	...	42·4	...	...	...	...	...	43·9	...	...	...
300	...	...	...	...	...	...	...	...	43·3	...	...	...
350	...	...	...	...	...	...	...	...	42·5	...	...	...
500	...	...	42·0	...	...	...	...	...	...	...	...	...
700	...	...	41·7	...	...	...	...	...	...	...	...	...

Date	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.	1904. May 31.
Time	1 a.m.	2 a.m.	3 a.m.	4 a.m.	5 a.m.	6 a.m.	7 a.m.	10.10 a.m.	11.45 a.m.	2.30 p.m.	2.20 p.m.	3 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	SE. of Old Pier.	Fort Augustus East Shore.
Wind	Calm.	SSE. 0–2.	NE. 0–1.	N. 0–¼.	Variable	Calm.	..	NE. 1–2.	..	..	..	..
Air Temp.	50·0	53·0	53·0	54·0	..	54·0	..	56·3	..	..	..	..
Depth. Feet.												
0	46·8	48·0	49·5	50·0	49·5	48·7	48·4	46·9	46·9	47·6	48·6	47·8
5	46·8	47·0	47·0	48·0	46·5	47·8	47·0	46·9	46·9	...	47·3	...
10	46·6	46·8	46·3	46·3	46·2	46·7	46·2	...	...	47·1	...	45·9
25	46·6	46·2	46·0	...	...	46·1	...	...	...	46·6	...	...
35	...	...	...	46·0	46·0	...	...	...	...	...	...	...
50	46·0	46·0	45·8	45·8	45·9	46·0	46·0	46·3	46·4	46·1	45·9	45·5
100	45·5	45·5	45·5	45·5	45·5	45·5	...	45·6	45·6	45·6	45·2	45·1
150	44·9	45·2	45·5	44·7	44·5	44·5	44·5	45·0	44·8	44·1	...	...
200	43·7	43·5	43·8	43·5	44·5	43·6	43·5	44·3	43·9	43·2	...	...

Date	1904. May 31.	1904. May 31.	1904. June 1.	1904. June 1.	1904. June 2.	1904. June 2.	1904. June 3.	1904. June 3.	1904. June 3.	1904. June 4.	1904. June 4.	1904. June 6.
Time	3.30 p.m.	4.15 p.m.	10.15 a.m.	3.15 p.m.	10.15 a.m.	4 p.m.	10 a.m.	12.15 p.m.	5 p.m.	11 a.m.	6 p.m.	11 a.m.
Position	100 Yards NE. of Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	100 Yards off Railway Pier.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	..	..	Calm.	SW. 1–2.	SW. 1–2.	SW. 1.	SW. 1.	..	SW. 1.	..	SW. 1–2. NE. ½.	..
Air Temp.	..	..	..	..	..	..	..	..	..	..	..	..
Depth. Feet.												
0	48·8	51·9	52·5	47·6	47·1	46·9	49·4	47·8	47·6	56·5	47·3	51·2
5	...	47·5	47·9	47·4	46·7	46·9	47·0	...	46·6	48·6	47·3	50·9
10	46·5	...	...	...	...	...	...	44·8	45·1	47·9	...	...
50	45·3	45·6	46·6	45·7	44·6	45·0	43·9	43·6	43·3	43·7	43·9	48·9
75	...	...	...	...	...	...	...	...	...	43·4	...	...
100	45·0	45·3	45·4	44·6	43·8	43·3	43·4	42·5	42·2	43·0	42·6	48·4
150	44·2	44·2	44·1	43·3	42·7	42·8	42·4	...	...	42·3	42·2	44·4
200	43·2	43·2	42·4	42·4	42·4	42·3	42·2	41·8	42·2	42·2	42·1	43·8
300	42·3	...	...	...	...	...	...	41·6	...	...	...	...
410	...	...	...	...	...	...	...	41·5	...	...	...	...

Date	1904. June 6.	1904. June 6.	1904. June 7.	1904. June 7.	1904. June 8.	1904. June 8.	1904. June 8.	1904. June 8.	1904. June 9.	1904. June 9.	1904. June 9.
Time	12 noon.	5.30 p.m.	10.45 a.m.	4 p.m.	10 a.m.	3 p.m.	3 p.m.	3 p.m.	11.30 a.m.	11.30 a.m.	11.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inverfarigaig.	Dores.	Yacht.	Inverfarigaig.	Dores.
Wind	..	NE. 4.	NE. 2.	..	NE. 1–2.	NE. 5.	..	NE. 1–2.	NE. 4–5.	..	NE. 1–3.
Air Temp.	53·4	..	..	..	..	..	..	..	..	..	..
Depth. Feet.											
0	50·8	51·6	54·2	52·5	51·4	50·8	46·8	43·1	50·7	46·8	44·3
5	50·8	51·9	54·0	52·4	51·4	50·8	...	...	...	...	...
10	...	...	...	51·7	...	...	46·8	43·1	...	46·8	44·3
20	...	...	...	...	51·3	50·7	...	...	50·7	...	...
25	...	...	...	...	...	...	46·8	...	...	46·5	...
50	48·9	49·7	49·6	49·9	49·7	50·7	46·4	43·0	50·7	46·2	44·1
75	...	...	...	...	...	...	...	...	...	...	43·8
100	48·2	48·4	48·8	48·8	49·6	50·2	45·3	42·8	50·3	44·1	43·3
150	44·2	44·5	44·5	44·4	44·3	44·2	44·2	...	45·5	43·5	...
200	43·8	43·8	43·5	43·5	43·5	43·3	43·9	42·3	42·9	43·0	42·8
285	....	...	...	...	...	...	...	...	...	...	42·8
300	...	...	...	...	...	...	43·8	42·1	...	42·4	...
400	...	...	...	...	...	...	...	...	...	42·0	...
500	...	...	...	...	...	...	...	...	...	42·0	...
600	...	..	...	...	...	...	...	...	...	42·0	...
700	...	...	...	...	...	...	...	...	...	41·9	...

Date	1904. June 9.	1904. June 9.	1904. June 11.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.
Time	2 p.m.	2 p.m.	7.30 a.m.	6.30 a.m.	9.35 a.m.	10.15 a.m.	10.30 a.m.	11.30 a.m.	11.30 a.m.	12.20 a.m.	12.30 a.m.	3.30 p.m.
Position	Inver-farigaig.	Dores.	Yacht.	Yacht.	Yacht.	400 Yards above Yacht.	Yacht.	Yacht.	Opposite Cherry Island West Side.	Yacht.	Opposite Railway Pier.	Yacht.
Wind	..	NE. 3–4.	NE. 1–2.	SW. ½–1.	SW. ½–1.	..	SW. 1.	SW. 2–3.	..	SW. 3–4.	..	SW. 1–2.
Air Temp.	..	..	..	..	60	..	59·0	62·0	..	64·5	..	62·5
Depth. Feet.												
0	46·8	44·2	51·0	52·0	...	51·8	...	...	51·8	51·1	51·4	...
10	46·8	44·2	...	...	...	51·6	...	...	...	...	...	...
20	...	...	50·7	51·5	...	...	...	...	...	...	...	...
25	46·8	...	...	...	...	51·1	...	...	51·0	...	51·0	...
50	46·2	43·8	50·4	50·8	49·9	50·0	49·6	48·9	50·0	48·2	50·0	47·8
75	...	...	...	48·7	47·9	48·1	47·9	47·5	48·0	47·0	48·0	46·4
85	...	...	...	...	47·6	47·0	47·3	46·4	46·8	45·0	46·6	44·0
95	...	...	...	...	...	...	44·6	44·4	...	43·9	...	43·4
100	44·2	43·3	49·3	47·3	45·2	44·8	44·1	43·9	44·2	43·4	44·0	43·2
105	...	...	...	45·2	44·1	...	43·9	43·5	...	...	...	43·1
110	...	...	...	44·7	43·6	...	43·6	43·2	...	...	...	43·0
125	...	...	...	44·1	43·4	...	43·3	42·6	...	43·0	...	42·8
150	44 0	...	48·4	43·6	...	43·2	...	...	43·0	...	43·0	...
175	...	...	44·0	43·1	...	...	...	...	...	...	42·8	...
200	43·2	42·9	43·0	43·1	...	43·0	...	...	42·8	...	...	...
300	43·2	42·6	...	...	...	42·8	...	...	42·8	...	42·8	...
400	...	...	...	..	...	...	...	...	42·6	...	...	...
450	...	...	...	...	...	...	...	...	42·2	...	...	...

Date	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 13.	1904. June 14.	1904. June 14.	1904. June 14.	1904. June 14.	1904. June 14.	1904. June 15.	1904. June 15.
Time	4 p.m.	4.35 p.m.	5 p.m.	5.35 p.m.	9.30 p m.	7.30 a.m.	10.45 a.m.	12 noon.	2.45 p.m.	4 p.m.	7.15 a.m.	10.45 a.m.
Position	Inver-farigaig.	Yacht.	Inver-farigaig, near Pier.	Yacht.	Yacht.	Yacht.	Yacht.	Opposite Railway Pier.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	Calm.	Calm.	SW. 1–2.	NE. ½.	SW. 1–2.	SW. 1–3.	SW. 0–3–4.	SW. 1–2.	W. 0–½.	SW. 1–2.	SW. 4.
Air Temp.	..	64·5	..	61·5	..	60·0	64·5	..	61·0	60·4	..	53·4
Depth. Feet.												
0	49·1	...	49·3	51·3	51·4	51·0	48·8	49·3	47·8	47·7	48·0	46·1
10	...	...	...	...	...	49·0	48·6	...	47·4	47·3	47·9	46·0
20	...	...	...	49·4	...	48·3	48·2	...	46·8	46·7	46·9	45·0
25	48·9	...	...	...	...	...	...	49·0	...	...	...	...
30	...	...	...	...	...	...	...	48·0	...	...	...	...
35	...	...	...	...	...	...	...	...	...	...	...	43·8
40	...	48·2	...	...	...	...	46·0	46·6	...	...	...	...
50	48·2	47·8	...	47·9	47·7	47·0	45·2	45·6	43·8	43·7	44·8	43·2
60	...	...	...	...	...	...	44·4	...	...	...	...	...
75	46·9	46·7	...	...	...	...	43·8	...	43·4	43·2	...	...
85	...	44·2	...	...	...	...	..	...	...	...	...	...
95	...	43·7	...	...	...	...	...	...	...	...	...	...
100	46·8	43·4	47·1	43·6	43·8	43·7	43 3	43·7	43·1	43·0	43·3	42·8
105	...	43·2	...	...	...	...	...	...	...	...	...	...
110	...	43·1	...	...	...	...	...	...	...	...	...	...
125	46·7	42·8	...	...	...	...	...	...	...	...	...	...
140	44·2	...	...	...	...	...	...	...	...	...	...	...
150	43·9	...	43·8	42·8	...	42·8	42·9	42·9	42·8	42·7	42·9	42·7
175	43·4	...	...	...	...	...	...	...	...	...	...	...
200	42·8	...	...	42·2	42·1	42·5	42·4	42·7	42·5	42·5	42·6	42·6
300	42·3	...	...	...	...	...	...	42·4	...	...	...	...
400	...	...	...	...	...	...	...	42·2	...	...	...	...
500	42·0	...	...	...	...	...	...	...	...	...	...	...
700	41·9	...	...	...	...	...	...	...	...	...	...	...

Date	1904. June 15.	1904. June 16.	1904. June 16.	1904. June 16.	1904. June 16.	1904. June 16.	1904. June 17.	1904. June 17.	1904. June 17.	1904. June 17.	1904. June 18.	1904. June 18.
Time	3.15 p.m.	7.15 a.m.	10.30 a.m.	3.15 p m.	5.15 p.m.	7.15 p.m.	11.30 a.m.	3.30 p.m.	12 noon.	4 p.m.	7.20 a.m.	8 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Opposite Cherry Island.	Between Yacht and Tarff.	Yacht.	Inverfarigaig near Pier.
Wind	SW. 2-5.	SW. 4-5.	SW. 5-6.	SW. 4-5.	SW. 2-3.	..	SW. 3-4.	SW. 3-4.	..	..	SW. 1-2.	..
Air Temp.	53·0	..	..	..	..	..	55·3	54·2	..	..	..	..
Depth. Feet.												
0	43·2	43·6	43·0	42·6	42·3	42·2	44·5	44·2	43·9	42·8	42·3	48·0
10	43·0	43·6	...	...	...	...	...	...	...	...	...	...
20	42·9	43·4	...	...	...	...	42·1	42·1	...	...	...	...
25	...	...	...	...	...	...	...	...	42·6	42·4	...	47·2
35	42·7	...	...	...	...	...	...	...	...	...	...	...
50	42·5	43·1	42·7	42·8	42·3	42·2	42·0	42·0	42·6	42·4	42·1	47·2
75	...	...	...	...	...	...	41·9	...	...	42·4	...	47·0
90	...	...	...	...	...	...	41·9	...	...	...	...	...
100	42·4	42·8	42·4	43·0	42·2	42·2	43·8	42·0	42·6	42·4	42·0	44·5
105	...	...	...	...	...	...	41·9	...	...	...	...	...
125	...	...	...	...	...	...	41·9	...	...	...	..	...
150	42·4	42·5	...	42·6	...	42·1	41·9	41·9	42·4	42·1	42·0	44·0
200	42·3	42·4	42·2	42·5	42·1	42·1	41·9	41·9	42·4	42·1	42·0	43·7
250	...	...	...	...	...	...	...	...	42·1	...	...	...
300	...	...	...	...	...	...	...	...	42·1	...	...	43·2
400	...	...	...	...	...	...	...	...	...	...	...	42·8

Date	1904. June 18.	1904. June 18.	1904. June 18.	1904. June 18.	1904. June 19.	1904. June 20.	1904. June 20.	1904. June 20.	1904. June 21.	1904. June 21.	1904. June 21.	1904. June 21.
Time	10 a m.	10 a.m.	2 p.m.	4.30 p.m.	12 noon	7.30 a.m.	10.30 a.m.	3.15 p.m.	7.30 a.m.	10.30 a.m.	3.30 p.m.	3.30 p.m.
Position	Inverfarigaig, West Side.	Yacht.	Inverfarigaig, East side.	Between Yacht and Tarff.	Yacht.	Yacht.	Inverfarigaig, East Shore.	Yacht.	Yacht.	Yacht.	Yacht.	Inverfarigaig.
Wind	..	..	..	SW. 2-3.	NE. 1.	SW. 1-3.	..	SW. 2-4.	SW. 0-1.	SW. 4.	SW. 2-3.	SW.
Air Temp.	..	..	..	51·6	..	..	..	52·0	..	..	56·0	..
Depth. Feet.												
0	47·8	42·8	48·1	43·6	43·4	43·3	48·0	43·0	43·5	43·0	43·5	48·1
20	...	...	...	41·9	...	...	...	42·8	...	...	...	...
25	47·8	...	48·1	...	...	...	47·5	...	43·0	...	...	48·0
50	47·8	42·0	48·0	41·9	43·3	43·0	46·7	42·5	42·8	43·0	42·3	47·4
75	47·1	...	47·2	...	...	...	46·4	...	...	...	42·2	47·1
100	46·8	42·0	44·0	41·9	43·0	43·0	46·1	42·4	42·7	42·6	42·2	46·0
120	...	...	...	...	43·0	...	...	...	...	...	...	...
150	45·5	...	43·8	...	...	43·0	46·1	42·2	42 5	...	42·2	45·6
200	44·8	42·0	43·8	41·9	43·0	43·5	44·0	42·2	42·4	42·5	42·1	45·0
300	43·2	...	43·2	...	...	...	43·5	...	...	...	...	43·8
350	...	...	...	...	...	...	42·7	...	...	...	...	...
400	42·5	...	42·5	...	...	...	...	...	...	...	...	43·5

Date	1904. June 21.	1904. June 22.	1904. June 22.	1904. June 22.	1904. June 22.	1904. June 22.	1904. June 23.	1904. June 23.	1904. June 23.	1904. June 23.	1904. June 23.	1904. June 23.
Time	11 a.m.	7.15 a.m.	10.15 a.m.	10 a.m.	3.30 p.m.	4 p.m.	10.30 a.m.	10 a.m.	10 a.m.	12 noon.	2.45 p.m.	4.45 p.m.
Position	Inver-farigaig.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Dores.	Inver-farigaig.	Yacht.	Yacht.
Wind	SW.	SW. 1–4.	SW. 3–4.	SW.	SW. 3–4.	SW.	SW. 1–3.	SW.	SW. 2.	..	SW. 2–3.	SW. 2–4.
Air Temp.	..	..	54·2	..	53·8	..	56·2	..	53·7	..	54·8	..
Depth. Feet.												
0	47·8	43·6	44·8	47·0	45·5	47·0	43·9	48·0	49·9	48·0	44·1	44·0
20	...	...	...	...	...	...	43·5	...	...	...	43·6	43·9
25	47·8	...	...	47·0	..	47·0	...	47·7	...	47·8	...	...
50	46·9	43·1	42·9	46·5	43·2	46·4	43·2	47·0	49·8	47·1	43·1	43·1
75	46·5	...	...	46·5	...	46·3	43·2	46·6	...	46·8	43·0	43·0
100	46·5	43·0	42·9	46·5	43·0	46·0	43·1	46·3	49·2	46·4	43·1	42·9
125	...	...	...	...	...	..	43·1	...	...	...	...	...
150	45·9	43·0	42·9	46·1	43·0	45·9	43·1	46·0	48·3	45·8	42·8	42·8
200	45·1	43·0	42·9	45·0	43·0	45·0	43·1	44·1	44·9	44·1	42·8	42·5
250	...	...	...	...	...	...	...	...	43·7	...	...	...
300	43·4	...	...	43·1	...	43·2	...	42·9	...	42·5	...	...
400	42·6	...	...	42·3	...	42·4	...	42·3	...	42·3	...	...
500	42·0	..	...	42·1	...	42·0	...	42·2	...	42·2	...	...
600	42·0	...	...	42·0	...	42·0	...	42·0	...	42·0	...	...
700	42·0	...	...	42·0	...	42·0	...	42·0	...	42·0	...	...

Date	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 24.	1904. June 25.	1904. June 25.	1904. June 25.	1904. June 25.
Time	7.45 a.m.	10.15 a.m.	10.45 a.m.	11 a.m.	11 a.m.	3 p.m.	3 p.m.	3.15 p.m.	7.45 a.m.	11 a.m.	11 a.m.	11 a.m.
Position	Yacht.	In Dores Bay.	Dores.	Inver-farigaig.	Yacht.	Yacht.	Inver-farigaig.	Dores.	Yacht.	Yacht.	Inver-farigaig.	Dores.
Wind	Calm.	NE. 0–½.	NE. 1.	NE.	NE. 1–3.	NE. 2–3.	NE.	NE. 1–2.	NE. 3–4.	NE. 3–4.	NE.	NE. 1.
Air Temp.	..	..	..	..	57·6	57·4	..	..	..	55·9	..	..
Depth. Feet.												
0	49·5	50·3	50·4	49·6	48·4	48·8	48·7	50·1	49·2	49·3	48·5	49·0
5	...	50·1	...	...	...	...	...	...	...	...	...	...
10	...	49·7	...	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	48·1	...	...	...	48·8	...	...
25	...	...	...	48·6	...	...	48·2	...	...	...	48·2	...
30	...	49·7	...	...	...	...	...	...	...	...	...	...
50	45·9	...	49·3	48·2	45·1	46·5	47·9	49·3	47·3	47·0	47·2	47·4
65	...	49·4	...	...	...	...	...	...	...	...	...	...
75	...	...	...	48·1	...	46·0	47·0	49·0	...	47·0	47·0	...
100	45·0	...	48·2	47·1	44·9	45·5	46·3	47·0	47·0	46·8	46·1	45·9
110	...	...	47·3	...	...	...	...	..	...	...	...	...
125	...	...	45·9	...	...	...	...	45·9	...	...	...	...
150	44·8	...	45·2	46·4	44·4	45·0	45·8	44·3	47·0	46·7	43·8	44·0
175	...	...	44·1	...	...	...	...	...	...	...	...	...
190	...	...	...	48·0	...	...	...	...	...	...	...	...
200	44·8	...	43·8	48·8*	44·0	44·6	44·0	43·7	46·7	46·7	43·8	43·4
210	...	...	...	45·9	...	...	...	...	...	...	...	...
220	...	...	...	43·8	...	44·1(230)	...	...	...	46·6(230)	...	...
250	...	...	43·3	43·5	...	...	...	43·0	...	...	...	...
300	...	...	42·8	42·3	...	...	42·6	42·7	...	...	43·8	42·8
400	...	...	...	42·1	...	...	42·3	...	...	...	43·8	...
500	...	...	...	42·0	...	...	42·1	...	...	...	42·7	...
600	...	...	...	42·0	...	...	42·0	...	...	...	42·3	...
700	...	...	...	42·0	...	...	42·0	...	...	...	42·0	...

* This observation was made three times.

Date	1904. June 25.	1904. June 25.	1904. June 25.	1904. June 26.	1904. June 27.	1904. June 27.	1904. June 27.	1904. June 27.	1904. June 28.	1904. June 28.	1904. June 29.	1904. June 29.
Time	12 noon.	3 p.m.	4 p.m.	11 a.m.	7 a.m.	4 p.m.	11 a.m.	3.30 p.m.	7.15 a.m.	10.5 a.m.	7.45 a.m.	8.30 a.m.
Position	Aldourie.	Yacht.	Inverfarigaig.	Yacht.	Yacht.	Yacht.	Inverfarigaig.	Inverfarigaig.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 1.	NE. 3-4.	Calm.	NE. 1.	Calm.	NE. ½-1.	NE.	..	NE. 0-½.	NE.	NE. 1.	NE. 1.
Air Temp.	50·4	55·8	..	..	..	..	..	..	58·0	..	57·8	..
Depth. Feet.												
0	49·2	50·1	48·7	49·0	51·3	53·2	50·4	49·8	51·6	52·1	52·2	52·7
20	...	48·8	...	...	...	...	...	...	...	...	...	...
25	48·2	...	48·3	...	...	...	49·7	48·8	...	...	...	...
50	47·0	47·1	47·2	47·9	49·0	49·0	48·8	48·1	49·9	49·8	50·1	...
75	...	47·2	47·1	...	...	...	47·3	47·0	...	...	...	...
100	...	47·0	46·0	47·6	47·9	48·0	45·6	46·7	47·8	47·6	49·7	49·7
150	...	47·0	44·0	47·3	45·7	45·0	44·0	45·0	44·0	44·5	46·7	46·3
200	..	46·9	43·8	44·4	43·8	43·2	43·6	43·8	42·7	42·9	43·6	...
240	..	...	...	43·9	...	...	...	...	...	...	...	...
300	...	...	43·8	...	...	...	42·8	42·8	...	...	...	...
400	...	...	43·8	...	...	...	42·3	42·3	...	...	...	...
500	...	...	42·4	...	...	...	42·1	42·1	..	...	...	...
600	...	...	42·0	...	...	...	42·0	42·0	...	...	...	...
700	...	...	42·0	...	...	...	42·0	42·0	...	...	...	...

Date	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.	1904. June 29.
Time	8 a.m	11 a.m.	11 a.m.	10.30 a.m.	11.30 a.m.	12.15 p.m.	3.30 p.m.	3.30 p.m.	3 p.m.	7 p.m.	5 p.m.	9.15 p.m.
Position	Dores.	Dores.	Inverfarigaig	Yacht.	Yacht.	Yacht.	Yacht.	Inverfarigaig.	Dores.	Dores.	Yacht.	Yacht.
Wind	Calm.	SE. 0-½.	Calm.	NE. ¼.	SW. ½-1.	..	..	Variable.	NE. 1.	NE. 0-½.	SW. 1-2.	Calm.
Air Temp.	53·8	66·0	..	..	..	..	..	..	65·7	61·0	..	..
Depth. Feet.												
0	49·0	52·1	53·1	53·7	55·2	55·1	50·6	50·0	49·0	48·5	50·5	51·8
5	...	48·8	...	...	...	...	...	...	...	...	...	...
10	...	48·0	...	...	...	...	...	...	48·0	48·3	...	...
20	...	...	...	...	...	...	...	...	...	...	...	50·0
25	...	...	48·9	...	...	...	...	48·2	...	...	...	...
50	46·7	46·9	48·2	50·0	...	...	49·9	48·0	46·9	47·0	...	49·5
75	...	...	46·8	...	...	...	...	47·2	...	...	...	...
100	46·0	46·2	46·2	49·5	49·5	...	49·3	46·8	46·3	46·2	...	48·8
115	...	...	...	...	...	49·7	...	...	...	...	...	...
125	...	...	...	...	...	49·0	...	...	...	...	...	46·8
150	45·3	45·3	44·9	46·0	46·0	45·9	45·5	45·0	45·7	45·7	...	44·4
175	44·9	44·9	...	...	...	44·0	...	...	...	...	...	...
200	43·6	...	43·8	43·8	...	...	43·4	43·7	43·9	44·7	...	43 2
250	43·0	...	...	...	...	...	42·8	...	43·1	43·2	...	...
300	42·8	42·8	43·1	...	...	...	...	43·1	42·9	43·0	...	...
400	...	...	42·8	...	...	...	...	42·9	...	...	...	...
500	...	...	42·2	...	...	...	...	42·3	...	...	...	...
600	...	...	42·0	...	...	...	...	42·0	...	...	...	...
700	...	...	42·0	...	...	...	...	42·0	...	...	...	...

Date	1904. June 30.	1904. June 30.	1904. June 30.	1904. June 30.	1904. June 30.	1904. June 30.	1904. June 30.	1904. June 30.	1904. July 1.	1904. July 1.	1904. July 1.	1904. July 2.
Time	7.30 a.m.	8 a.m.	11 a.m.	11 a.m.	11.45 a.m.	2.30 p.m.	3 p.m.	4 p.m.	7.15 a.m.	12.30 p.m.	4 p.m.	7.30 a.m.
Position	Yacht.	Dores.	Dores.	Inver-farigaig.	Yacht.	Dores.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	Variable.	Calm.	Calm.	SW. 1-2.	SW. 1-2.	S.W.	SSW. 1-3.	SW. 1-2.	SW. 3.	..	SW. 1-3.
Air Temp.	..	55·3	67·2	..	..	65·8	..	..	..	..	..	54·8
Depth. Feet.												
0	53·3	49·0	50·3	53·2	53·0	49·1	52·5	49·9	49·2	47·9	45·1	44·3
5	...	...	48·2	...	...	...	...	...	...	...	...	...
10	...	...	48·1	...	...	...	..	...	...	...	...	...
25	...	...	...	48·8	...	...	52·0	...	47·7	...	...	...
50	49·7	46·9	46·9	48·0	49·5	47·2	51·8	49·1	45·6	46·0	44·0	43·9
75	...	..	...	47·3	...	...	48·6	...	...	...	...	...
100	48·2	46·3	47·0	46·8	46·7	46·9	46·8	45·0	44·2	44·2	44·0	43·7
125	...	...	...	...	45·0	...	...	...	...	...	...	...
150	44·7	45·8	46·2	45 0	44·5	...	44·2	44·3	45·0	43·9	43·6	43·3
175	...	...	...	...	44 1	...	...	...	...	...	...	...
200	43·4	43·5	45·7	43·8	44·0	46·2	43·4	43·7	43·4	43·5	43·2	43·3
250	...	43·0	43·3	...	...	45·9	...	...	...	..	...	...
300	...	42·8	43·0	43·0	...	43·8	42·8	...	...	...	...	..
400	...	...	...	42·8	...	...	42·3	...	...	...	...	...
500	...	...	...	42·2	...	...	42·1	...	...	...	...	...
600	...	...	...	42·0	...	...	42·0	...	...	...	...	...
700	...	...	...	42·0	...	...	42·0	...	...	..	...	...

Date	1904. July 2.	1904. July 2.	1904. July 2.	1904. July 3.	1904. July 4.	1904. July 4.	1904. July 4.	1904. July 4.	1904. July 4.	1904. July 4.	1904. July 5.	1904. July 5.
Time	11 a.m.	2.30 p.m.	5 45 p.m.	10.30 a.m.	7.35 a.m.	11 a.m.	11 a.m.	3 p.m.	3 p.m.	4 p.m.	7.20 a.m.	10.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.
Wind	SW. 3.	SW. 2.	WSW. 2.	SW. 1-2.	..	SW. 2.	SW.	SW. 3.	..	SW. 3.	SW. 2-3.	SW. 2.
Air Temp.	59·0	55·1	52·0	54·0	..	53·5	..	..	..	..	..	56·5
Depth. Feet.												
0	44·1	45·7	46·2	45·6	47·6	47·6	50·4	47·4	50·3	47·4	46·6	46·9
25	...	...	...	...	...	...	50·4	...	50·2	...	...	...
50	43·7	44·0	44·5	45·0	47·3	47·3	49·8	47·0	49·7	46·9	46·0	45·7
75	...	...	...	...	...	...	48·7	..	48·7	...	...	...
100	44·0	43·9	44·3	45·0	47·0	47·0	48·7	46·8	48·7	46·5	45·4	45·2
150	43·3	43·5	44·0	44·0	46·7	46·6	43·9	45·7	44·1	45·4	44·3	44·0
200	43·1	43·4	44·0	43·5	46·1	45·3	46·8*	44·2	43·8	44·1	43·7	43·0
300	...	...	...	...	...	...	42·7	...	42·7	...	...	...
400	...	...	...	...	...	...	42·4	...	42·6	...	...	...
500	...	...	...	...	...	...	42·1	...	42·2	...	...	...
600	...	...	...	...	...	...	42·0	...	42·0	...	...	...
700	...	...	...	...	...	...	42·0	...	42·0	...	...	...

* This observation was made twice.

Date	1904. July 5.	1904. July 5.	1904. July 5.	1904. July 6.	1904. July 6.	1904. July 6.	1904. July 6.	1904. July 6.	1904. July 7.	1904. July 7.	1904. July 7.	1904. July 7.
Time	10 a.m.	2.30 p.m	6.30 p.m.	7.15 a.m.	11 a.m.	2.30 p.m.	3 p.m.	6 p.m.	7.30 a.m.	10.30 a.m.	11 a.m.	12.30 p.m.
Position	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.
Wind	SW.	SW. 2.	..	SW. 3.	SW. 4–6.	SW. 3.	SW.	SW. 3.	SW. 1.	SW. 3–4.	SW.	SW. 3–4.
Air Temp.	..	..	..	..	60·0	..	..	..	..	..	..	..
Depth. Feet.												
0	49·5	46·6	46·1	44·6	43·6	43·1	49·0	44·4	44·0	43·6	49·0	43·6
25	49·0	...	...	...	...	...	49·0	...	...	...	48·6	...
50	48·9	45·6	...	43·6	43·0	42·5	48·9	43·0	43·4	43·0	48·0	42·9
75	48·9	...	...	...	...	...	48·6	...	...	...	47·4	...
100	48·9	44·6	44·3	43·0	42·5	42·4	48·2	42·8	43·0	42·9	47·2	42·8
150	46·1	...	...	42·8	42·4	42·3	47·6	43·4	42·5	42·6	47·0	42 6
200	44·1	43·0	42·6	42·4	42·3	42·2	44·8	42·4	42·4	42·4	46·2	42·4
300	43·0	...	...	...	...	...	43·0	...	...	...	42·9	...
400	42·7	...	...	...	...	...	42·6	...	...	...	42·3	...
500	42·1	...	...	...	...	...	42·2	...	...	...	42·2	...
600	42·0	...	...	...	...	...	42·0	...	...	...	42·0	...
700	42·0	...	...	...	...	...	42·0	...	...	...	42·0	...

Date	1904. July 7.	1904. July 7.	1904. July 8.	1904. July 8.	1904. July 8.	1904. July 8.	1904. July 9.	1904. July 9.	1904. July 9.	1904. July 9.	1904. July 9.	1904. July 10.
Time	3 p.m.	5.45 p.m.	7.20 a.m.	11 a.m.	2 p.m.	5.30 p.m.	7.30 a.m.	11.15 a.m.	2.35 p.m.	4.30 p.m.	6 p.m.	11 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2.	SW. 2.	SW. 3.	SW. 4–5.	SW. 3.	SW. 2–3.	SW. 1.	SW. 1.	SW. 1–2.	SW. 2.	SW. 1.	SW. 1.
Air Temp.	..	53·0	51·5	..	..	54·8	54·5	60·0	..	54·8	57·0	..
Depth. Feet.												
0	43·2	43·2	42·5	43·6	43·4	43·4	45·6	44·5	45·4	46·8	45·9	49·5
50	42·7	42·8	42·4	42·9	42·9	42·6	43·6	43·6	44·6	44·0	44·4	47·7
100	42·6	42·7	42·3	42·8	42·7	42·4	43·5	43·4	44·0	44·0	44·1	47·1
150	42·4	42·3	42·2	42·7	42 5	42·2	43·2	43·0	43·9	43·8	44·0	46·8
200	42·3	42·2	42·2	42·6	...	42·2	43·0	43 0	43·6	43·8	44·0	45·7

Date	1904. July 10.	1904. July 11.	1904. July 11.	1904. July 11.	1904. July 12.	1904. July 12.	1904. July 12.	1904. July 12.	1904. July 13.	1904. July 13.	1904. July 13.	1904. July 13.
Time	12.20 p.m.	7.30 a.m.	11.30 a.m.	3.45 p.m.	8 a.m.	11.30 a.m.	3.30 p.m.	6 p.m.	8 a.m.	12.15 p.m.	3 p.m.	3.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.
Wind	SW. 1.	Calm.	NE. 4.	NE. 4.	NE. 3–4.	NE. 4–5.	S. 2–3.	S. 2–3.	Calm.	S. 0–1.	..	SW. 4–5.
Air Temp.	..	..	..	60·0	..	62·0	61·0	60·0	..	64·2	69·9	..
Depth. Feet.												
0	49·5	52·4	51·6	58·4	51·6	53·7	57·1	56·4	54·6	56·7	54·1	51·7
20	...	...	...	50·8	...	...	...	...	...	...	...	...
25	...	...	...	50·8	...	...	51·4	51·6	...	...	52·8	...
50	47·3	48·0	48·0	50·5	49·8	50·5	51·2	51·3	54·5	51·2	50·1	50·8
75	...	...	...	...	...	...	...	...	...	...	49·6	...
100	47·1	47·6	47·8	48·1	49·7	50·1	50·4	51·0	49·3	48·0	48·1	48·2
125	...	...	...	...	...	...	...	47·0	...	...	...	...
150	46·9	47·3	47·1	47·5	49·6	50·0	49·8	46·8	45·0	44·2	46·7	47·1
175	...	...	...	...	...	...	45·1	...	...	...	...	43·4
200	45·3	45·4	45·5	44·8	45·6	43·8	44·5	44·3	44·8	42·8	45·4	42·8
300	...	...	...	...	...	...	...	...	...	...	43·8	...
400	...	...	..	...	...	...	...	...	...	...	42·9	...
500	...	...	...	...	...	...	...	...	...	...	42·1	...
600	...	...	...	...	...	...	...	...	...	...	42·0	...

Date	1904. July 13.	1904. July 14.	1904. July 14.	1904. July 14.	1904. July 14.	1904. July 14.	1904. July 14.	1904. July 14.	1904. July 15.	1904. July 15.	1904. July 15.	1904. July 16.
Time	5 p.m.	8 a.m.	11 a.m.	11.30 a.m.	3 p.m.	3 p.m.	5 p.m.	4.30 p.m.	10 a.m.	11.45 a.m.	4 p.m.	8 a.m.
Position	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Between Railway Pier and Glendoe.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 4-5.	SW. 2.	SW.	SW. 1-2.	SW. 1.	SW.	SW-W.1-4.	SW. 1.	SW. 2-3.	SW. 2-3.	SW. 2-3.	SW. 2.
Air Temp.	64·0	..	..	..	..	61·1	61·2	58·8	65·0	61·0	..	..
Depth. Feet.												
0	51·6	50·8	52·0	50·0	49·8	52·0	50·8	49·2	47·1	46·7	46·8	47·4
25	...	...	51·8	...	...	52·0	47·4	...	...	...	...	...
50	49·8	47·8	51·0	47·2	46·0	51·8	45·8	46·4	46·4	46·6	46·0	46·2
75	...	...	49·8	...	...	49·8	...	...	...	...	...	...
100	46·2	45·1	48·4	44·8	44·4	48·2	...	44·4	45·8	46·3	45·3	46·0
150	44·1	45·0	46·8	43·2	43·0	46·8	42·3	...	45·0	45·5	45·0	45·8
175	44·0	...	...	...	...	...	...	...	...	...	...	...
200	42·8	44·3	45·8	42·5	42·3	44·9	42·5	42·6	44·4	45·0	44·6	45·5
300	...	...	44·0	...	...	43·3	...	42·2	...	...	...	...
400	...	...	43·0	...	...	43·0	...	...	...	...	...	...
500	...	...	42·6	...	...	42·8	...	...	...	...	...	...
600	...	...	42·2	...	...	42·2	...	...	...	...	...	...
700	...	...	42·1	...	...	42·1	...	...	...	...	...	...

Date	1904. July 16.	1904. July 16.	1904. July 16.	1904. July 16.	1904. July 16.	1904. July 17.	1904. July 18.	1904. July 18.	1904. July 18.	1904. July 18.	1904. July 18.	1904. July 18.
Time	11.20 am.	3 p.m.	3 p.m.	4 p.m.	4·45 p.m.	1 p.m.	8 a.m.	11 a.m.	12 noon.	3 p.m.	3.30 p.m.	5 p.m.
Position	Yacht.	Yacht.	Inver-farigaig.	Between Railway Pier and Glendoe.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.
Wind	SW. 3.	SW. 2.	SW.	SW. 2-3.	SW. 1-2.	NE. 1.	Calm.	NE. 0-½.	NE. 1.	..	NE. 1.	NE. 2-3.
Air Temp.	..	..	59·0	60·0	60·0	68·0	..	64·0	68·0	75·0	69·0	66·0
Depth. Feet.												
0	46·6	47·6	51·2	49·2	47·6	53·8	50·8	56·2	54·7	55·3	60·1	56·0
5	...	...	...	...	...	...	...	...	...	...	54·2	...
10	...	...	...	...	...	...	...	...	...	..	53·9	...
25	...	...	51·1	...	...	...	...	52·5	49·5	52·1	50·0	50·0
50	46·7	46·3	51·0	46·5	46·8	48·4	50·3	52·0	49·2	51·0	49·2	49·8
75	...	...	50·8	...	...	...	...	50·1	...	50·8	...	...
100	45·9	46·0	50·2	46·0	46·3	47·0	49·0	49·8	49·0	47·8	49·0	49·0
150	45·6	45·8	46·8	...	45·5	46·3	47·8	45·6	48·1	45·8	48·2	48·4
200	45·5	45·2	44·0	45·2	45·0	46·2	46·5	44·1	46·4	44·6	46·0	46·5
300	...	...	43·4	43·8	...	...	...	43·4	...	43·4	...	...
400	...	...	43·0	...	...	...	...	43·1	...	43·0	...	...
500	...	...	42·7	...	...	...	...	42·9	...	42·8	...	...
600	...	...	42·3	...	...	...	...	42·4	...	42·4	...	...
700	...	...	42·1	...	...	...	...	42·2	...	42·2	...	...

Date	1904. July 19.	1904. July 19.	1904. July 19.	1904. July 19.	1904. July 19.	1904. July 19.	1904. July 20.	1904. July 20.	1904. July 20.	1904. July 20.	1904. July 20.	1904. July 21.
Time	7.25 a.m.	10.45 a.m.	11 a.m.	2.30 p.m.	5 p.m.	7.15 a.m.	11.15 a.m.	11 a.m.	2.45 p.m.	3 p.m.	6 p.m.	7.30 a.m.
Position	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.
Wind	NE. 1-2.	NE. 2.	NE.	NE. 5.	NE. 5.	NE. 4.	NE. 5-6.	NE.	NE. 4.	NE.	NE. 1.	NE. 1.
Air Temp.	60·5	61·5	59·0	..	..	59·0	59·5	60·0	62·0	61·0	60·0	55·0
Depth. Feet.												
0	53·2	53·2	53·2	53·4	53·7	54·3	54·0	52·3	54·0	51·5	55·3	54·8
25	...	...	52·6	...	...	...	...	51·9	...	51·3	...	54·0
50	52·7	53·1	51·1	53·2	53·2	53·3	53·8	51·8	53·8	51·0	53·7	53·3
75	...	...	50·0	...	...	...	...	50·7	...	50·0	...	...
100	51·1	50·9	48·1	53·0	51·8	53·0	53·0	49·0	53·3	49·6	53·2	50·2
	...	...	...	...	...	...	...	...	...	...	...	47·6
150	48·5	53·0*	45·2	49·0	51·0	48·0	48·0	46·2	51·8	46·0	48·9	44·6
200	44·6	51·5	44·7	48·2	49·4	43·7	43·7	45·2	44·8	45·0	44·1	43·0
300	...	...	43·0	...	...	..	...	43·5	...	43·3	...	...
400	...	...	42·9	...	...	...	...	42·9	...	42·8	...	...
500	...	...	42·8	...	...	...	...	42·6	...	42·3	...	...
600	...	...	42·4	...	...	...	...	42·4	...	42·3	...	...
700	...	...	42·2	...	...	...	...	42·2	...	42·1	...	...

Date	1904. July 21.	1904. July 21.	1904. July 21.	1904. July 21.	1904. July 21.	1904. July 22.	1904. July 22.	1904. July 22.	1904. July 22.	1904. July 22.	1904. July 22.	1904. July 22.
Time	10.30 a.m.	11 a.m.	2 p.m.	3 p.m.	7 p.m.	7.20 a.m.	10.30 a.m.	11 a.m.	2.30 p.m.	3 p.m.	4.30 p.m.	4.35 p.m.
Position	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig off River.
Wind	NE. 2.	NE.	NE. 3.	NE.	NE. 4.	NE. 1.	NE. 2.	NE.	NE. 4.	NE.	NE.	..
Air Temp.	58·0	59·0	60·0	59·0	..	..	61·0	58·1	..	57·0	..	..
Depth. Feet.												
0	54·5	52·3	55·1	52·8	54·6	55·6	55·6	53·0	55·6	52·8	52·8	52·2
10	...	...	...	...	...	...	...	...	...	...	...	52·2
25	...	52·0	...	52·2	...	...	...	52·5	...	52·4	...	52·2
50	53·2	51·8	53·6	51·5	54·4	53·8	53·8	52·0	54·0	52·2	54·5	52·2
75	...	51·2	...	50·9	...	...	...	52·0	...	52·0	...	52·2
100	51·0	50·8	52·3	49·0	53·0	50·0	51·2	50·0	53·2	50·0	52·0	52·2
125	47·1	...	...	...	...	...	...	...	...	...	...	...
150	44·8	46·5	45·0	46·0	45·5	44·3	44·3	47·0	46·0	46·8	51·8	...
200	43·0	45·0	43·1	45·0	43·1	43·0	43·1	45·2	44·8	45·2	51·0	...
300	...	43·5	...	43·3	...	...	...	44·0	...	44·0	...	...
400	...	43·0	...	43·0	...	...	...	43·0	...	42·9	...	...
500	...	42·8	...	42·8	...	...	...	43·0	...	42·9	...	..
600	...	42·6	...	42·6	...	...	...	42·9	...	42·6	...	..
700	...	42·2	...	42·2	...	...	...	42·4	...	42·3	...	...

* At 12 noon the Temperature at 150 ft. was 49·0°.

Date	1904. July 22.	1904. July 23.	1904. July 23.	1904. July 23.	1904. July 23.	1904. July 23.	1904. July 23.	1904. July 23.	1904. July 24.	1904. July 24.	1904. July 25.	1904. July 25.
Time	7.15 p.m.	7.20 a.m.	11 a.m.	11 a.m.	3 p.m.	3 p.m.	4.15 p.m.	7 p.m.	10.30 a.m.	4 p.m.	7.15 a.m.	11 a.m.
Position	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Inver-farigaig Mid-Loch.	Inver-farigaig off River.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.
Wind	NE. 2.	NE. ½–1.	NE. 1.	NE. 0–1.	NE. 1.	NE. 0–1.	NE.	NE. 3.	Calm.	NNE. 0–½.	NE. 1–2.	NE. 0–1.
Air Temp.	..	..	..	62·0	..	59·0	..	..	68·0	66·5	60·0	60·0
Depth. Feet.												
0	56·6	56·4	56·6	54·8	58·2	53·2	57·2	57·0	57·9	60·2	57·3	55·8
10	...	...	...	..	...	...	...	...	...	55·0	...	...
20	...	...	...	...	54·0	...	...	55·8	...	...	...	...
25	...	...	54·8	53·0	...	53·0	...	...	...	...	...	54·2
50	54·5	54·0	54·4	51·8	53·8	52·6	...	53·1	54·5	54·4	55·5	52·0
75	...	...	54·1	50·2	52·5	52·0	...	...	...	...	...	50·1
100	53·8	53·3	49·1	49·0	46·3	51·0	...	46·7	46·9	46·8	54·3	49·0
150	45·8	45·5	46·8	46·2	45·6	46·1	...	45·7	45·6	46·6	46·6	46·3
200	44·8	44·2	45·4	44·8	45·4	44·9	...	45·5	44·6	44·6	44·9	45·0
300	...	...	...	43·5	...	43·2	...	...	...	...	...	43·0
400	...	...	...	43·0	...	43·0	...	...	...	...	...	42·9
500	...	...	...	43·0	...	43·0	...	...	...	...	...	42·8
600	...	...	...	42·9	...	42·8	...	...	...	...	...	42·5
700	...	...	...	42·6	...	42·5	...	...	...	...	...	42·4

Date	1904. July 25.	1904. July 25.	1904. July 25.	1904. July 25.	1904. July 26.	1904. July 26.	1904. July 26.	1904. July 26.	1904. July 26.	1904. July 26.	1904. July 27.	1904. July 27.
Time	11 a.m.	2 p.m.	3 p.m.	7 p.m.	7.20 a.m.	10.45 a.m.	11 a.m.	11.40 a.m.	2.30 p.m.	6.30 p.m.	7.30 a.m.	10 a.m.
Position	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 2.	NE. 2.	..	NE. 1.	NE. ½.	NE. ½–1.	NE.	NE. 3–4.	NE. 5.	NE. 3–4.	Calm.	NE. 1.
Air Temp.	61·0	60·0	60·0	..	58·5	62·0	57·8	..	61·0	59·0	..	61·0
Depth. Feet.												
0	57·4	57·7	55·0	58·0	57·0	57·2	54·2	...	56·8	56·8	56·0	56·0
20	...	56·0	...	56·4	...	...	...	...	...	...	...	...
25	...	...	53·2	...	...	56·0	54·0	...	56·8	56·8	55·2	55·4
50	55·2	55·2	53·0	55·0	54·9	55·0	53·0	...	56·6	56·3	55·1	54·9
60	...	...	...	...	...	...	...	54·6	...	...	...	...
65	...	...	...	...	...	...	...	52·6	...	...	...	...
70	...	...	..	...	...	...	...	49·9	...	...	...	...
75	...	...	51·2	...	...	...	51·3	49·5	54·4	56·0	55·0	54·9
85	...	...	...	...	...	...	...	...	...	...	54·6	...
100	50·8	53·1	48·9	50·4	48·0	48·5	49·2	...	48·9	49·8	53·6	54·3
125	...	...	...	47·9	...	...	...	47·7	48·2	...	49·0	49·4
150	46·5	46·6	46·1	46·7	47·2	47·1	46·2	...	47·7	48·0	47·8	48·4
175	...	...	...	...	...	...	...	46·0	...	...	46·4	46·7
200	45·2	44·8	44·9	45·6	44·6	45·5	44·8	...	45·6	44·6	45·4	45·6
230	...	...	...	...	...	...	...	...	44·0	43·7	...	44·4
235	...	...	...	44·9	43·6	43·6	...	...	...	...	43·6	...
300	...	...	43·2	...	...	...	43·2	...	...	...	...	...
400	...	...	43·0	..	...	...	43·0	...	...	...	...	...
500	...	...	42·9	...	...	...	42·8	...	...	...	...	...
600	...	...	42·5	...	...	...	42·7	...	...	...	...	...
700	...	...	42·4	...	...	...	42·3	...	...	...	...	...

Date	1904. July 27.	1904. July 27.	1904. July 27.	1904. July 27.	1904. July 27.	1904. July 28.	1904. July 28.	1904. July 28.	1904. July 28.	1904. July 28.	1904. July 29.	1904. July 29.
Time	11 a.m.	1 p.m.	3 p.m.	4 p.m.	7 p.m.	11 a.m.	11.15 a.m.	1 p.m.	3 p.m.	5 p.m.	7.15 a.m.	10 a.m.
Position	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.
Wind	..	NE. 2.	NE.	NE. 3.	NE. 3-4.	NE.	NE. 4.	NE. 4.	..	NE. 5.	NE. 1-2.	Variable.
Air Temp.	..	..	58·5	..	61·2	57·2	61·0	61·5	60·0	62·0	..	..
Depth. Feet.												
0	55·0	56·5	54·2	56·6	56·7	54·3	56·8	56·9	54·8	56·7	57·1	59·5
25	53·2	55·1	53·2	55·0	56·6	54·1	56·6	56·6	53·8	56·7	56·6	56·5
50	53·0	54·9	53·0	54·4	55·7	54·0	56·1	56·1	53·8	56·7	56·1	56·1
75	51·2	54·8	52·1	54·3	54·6	51·0	55·4	55·2	52·5	56·4	55·9	55·8
85	...	...	...	...	...	...	51·8	...	...	...	...	...
100	50·0	54·5	50·0	54·1	54·5	48·6	49·1	49·0	49·2	49·2	55·4	55·0
110	...	...	...	...	51·3	...	...	...	...	...	...	...
125	...	49·0	...	48·9	48·8	...	47·2	47·0	...	47·7	48·3	48·2
150	47·0	48·1	47·1	48·4	47·3	46·1	45·4	45·3	46·4	45·4	46·8	46·3
175	...	45·8	...	45·9	45·6	...	43·8	43·8	...	44·2	45·4	44·6
200	45·0	45·1	45·2	44·0	44·0	45·0	43·4	43·3	45·2	43·9	44·0	43·9
225	...	...	...	...	...	...	43·0	43·0	...	43·6	43·4	...
230	...	43·6(235)	...	43·6(235)	43·9	...	...	...	...	...	...	43·7
300	43·6	...	43·7	...	...	43·2	...	...	43·1	...	...	...
400	43·0	...	43·0	...	...	43·0	...	...	42·9	...	...	...
500	42·9	...	42·8	...	...	42·8	...	...	42·7	...	...	...
600	42·6	...	42·6	...	...	42·7	...	...	42·7	...	...	...
700	42·3	...	42·4	...	...	42·4	...	...	42·4	...	...	...

Date	1904. July 29.	1904. July 29.	1904. July 29.	1904. July 29.	1904. July 29.	1904. July 30.	1904. July 30.	1904. July 30.	1904. July 30.	1904. July 30.	1904. July 30.	1904. July 31.
Time	11 a.m.	1 p.m.	3 p.m.	4 p.m.	7.5 p.m.	7.15 a.m.	10 a.m.	11 a.m.	1 p.m.	4 p.m.	9 p.m.	11 a.m.
Position	Inver-farigaig.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW.	Calm.	SW.	SW. ½.	SW. 1.	NE. ½.	SW. ½.	SW.	SSW. 0-1.	SW. ½.	Calm.	SW. 1.
Air Temp.	65·0	68·0	67·0	67·5	64·0	63·0	67·2	60·0	72·2	73·5	..	67·0
Depth. Feet.												
0	54·6	59·8	55·2	58·1	56·5	56·8	57·7	55·8	56·7	56·2	55·5	55·6
25	54·1	56·3	54·1	56·0	55·2	55·7	55·5	55·0	55·3	55·2	54·7	54·9
50	53·8	55·8	53·4	55·6	55·5	55·2	55·4	54·0	52·9	50·4	49·6	54·8
75	52·0	55·3	52·2	54·9	53·8	49·7	48·6	50·8	48·3	48·4	48·0	49·9
100	49·0	54·6	49·0	49·1	48·7	47·6	48·5	49·0	47·3	46·9	47·0	48·5
125	...	47·2	...	47·0	47·1	45·8	46·2	...	46·3	46·0	46·1	47·8
150	47·0	46·0	47·0	46·1	46·0	45·2	45·8	46·3	46·0	45·9	45·8	47·0
175	...	45·3	...	45·3	45·3	44·5	45·5	...	45·5	45·6	45·7	46·7
200	45·0	44·2	45·0	44·3	44·3	44·0	45·1	44·8	45·2	44·8	45·1	46·0
225	...	43·6	...	43·6	43·7	43·7	44·4	...	44·4	44·4	44·1	45·6
300	43·8	...	43·3	...	...	...	...	43·2	...	...	...	...
400	43·0	...	43·0	...	...	...	...	43·0	...	...	...	...
500	42·8	...	42·8	...	...	...	...	42·8	...	...	...	...
600	42·7	...	42·7	...	...	...	...	42·7	...	...	...	...
700	42·3	...	42·3	...	...	...	...	42·3	...	...	...	...

Date	1904. July 31.	1904. July 31.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.
Time	2 p.m.	4.30 p.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	10 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Portclair.
Wind	SW. 1-2.	SW. 0-½.	SW. 1.	SW. 2-3.	SW. 2.	SW. 2.	SW. 2.	Calm.	Calm.	SW. 0-½.	Calm.	SW. 3.
Air Temp.	..	63·3	59·3	60·0	..	60·4	64·0	63·8	..	60·0	60·3	56·7
Depth. Feet.												
0	55·1	56·6	51·9	51·2	50·7	50·6	50·6	52·4	53·6	52·6	53·4	54·5
25	53·8	54·1	51·2	51·1	50·1	50·1	50·1	49·9	49·9	50·3	50·2	54·0
50	52·9	51·0	51·0	50·0	49·9	49·6	48·6	49·2	49·8	49·9	50·1	51·6
75	49·1	49·5	50·8	49·2	49·2	48·2	47·8	47·9	49·4	49·6	49·8	...
100	48·8	49·0	50·6	49·0	48·8	47·5	47·2	47·5	48·3	48·7	49·0	49·1
125	48·1	48·7	49·0	47·5	48·0	46·4	46·2	47·2	47·3	47·5	47·7	...
150	47·3	48·1	47·2	47·0	46·3	46·0	46·0	45·8	46·4	46·3	46·0	46·3
175	47·1	47·8	46·0	45·8	45·0	44·8	44·5	45·0	45·7	45·9	45·0	...
200	46·5	46·7	45·6	44·7	44·5	44·2	44·2	44·2	44·0	44·5	44·0	43·9
225	46·1	45·9	45·4	44·0	44·0	43·8	43·8	43·5	43·7	44·0	43·5	...
350	...	...	...	...	...	...	...	...	...	...	...	43·0
550	...	...	...	...	...	...	...	...	...	...	...	42·5

Date	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 1.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.
Time	11 a.m.	12 noon.	1 p.m.	2 p.m.	2.40 p.m.	5 p.m.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.
Position	Altsigh.	Inver-farigaig.	Temple Pier.	Abriachan	Aldourie.	Lenie.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2-3.	SW. 1-2.	SW. 1-2.	SW. 2.	SW. 2.	SW. 3.	Calm.	Calm.	Calm.	Calm.	SW. 0-½.	SW. 1.
Air Temp.	57·1	59·0	57·1	..	..	..	..	58·0	59·0	59·0	61·3	62·0
Depth. Feet.												
0	55·5	56·4	55·8	55·9	56·3	55·0	51·8	53·0	52·1	52·1	51·9	52·1
25	54·6	55·4	54·7	55·6	55·9	54·6	51·2	50·6	50·5	49·9	50·9	50·4
50	53·4	54·4	54·4	55·1	56·0	54·6	50·4	50·2	50·2	49·1	49·9	49·1
75	...	...	...	...	...	...	50·0	50·0	49·9	48·3	49·6	47·4
100	49·7	49·6	53·3	54·6	55·3	51·3	49·7	49·1	48·1	47·8	49·9	46·8
125	...	...	...	...	...	...	49·3	46·5	46·7	46·0	46·0	45·3
140	...	...	...	...	48·1	...	...	...	...	...	...	...
150	47·0	45·9	46·0	46·8	...	...	46·0	45·3	45·6	45·3	45·3	44·4
175	...	...	...	...	...	...	45·1	45·0	45·0	44·9	44·2	44·0
200	46·0(210)	44·1	44·3	44·8	...	44·7	44·2	44·0	44·1	44·0	43·7	43·6
225	...	...	...	...	...	...	43·4	43·7	43·8	43·5	43·6	43·4
250	...	...	...	43·8	...	...	...	...	...	...	...	...
300	...	...	...	...	...	43·1	...	...	...	...	...	...
350	43·1	43·2	42·9	42·7	...	...	...	...	...	...	...	...
500	...	...	...	...	...	42·4	...	...	...	...	...	...
550	42·4	42·6	42·3	...	...	...	...	...	...	...	...	...
700	...	...	...	...	...	42·0	...	...	...	...	...	...

Date	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 2.	1904. Aug. 3.
Time	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	10 a.m.	11 a.m.	12.30 p.m.	1.15 p.m.	2 p.m.	2 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Port Clair.	Altsigh.	Inver-farigaig.	Temple Pier.	Dores.	Yacht.
Wind	SW. 3.	SW. 2.	SW. 1.	Calm.	Calm.	NE. ½.	..	SW. ½.	Calm.	SW. 1-3.	SW. 2-3.	NNE. 1.
Air Temp.	62·0	61·5	61·8	60·0	55·5	60·0	..	..	..	..	..	57·0
Depth. Feet.												
0	51·6	51·9	52·1	53·8	53·9	56·1	54·9	56·2	57·8	56·7	56·4	52·4
25	50·5	51·3	51·3	51·8	52·1	52·2	...	54·5	54·6	55·3	...	52·2
50	50·1	49·8	50·9	51·1	51·4	51·9	52·5	54·1	54·3	...	56·0	52·1
75	48·8	49·6	49·8	50·6	51·1	51·5	...	...	...	...	...	51·5
100	46·5	49·2	49·8	50·2	50·5	51·0	50·0	50·0	48·4	50·0	47·6	51·2
125	46·2	47·8	48·5	50·0	50·2	50·5	...	...	...	...	...	50·2
150	47·8	47·3	48·2	49·0	49·1	49·7	47·5	46·8	46·0	...	46·1	49·0
175	47·5	46·5	47·0	48·7	48·3	48·0	...	...	...	...	...	46·9
200	47·3	45·2	46·6	47·1	47·0	46·9	42·8	44·7	44·6	44·6	...	45·0
225	47·2	44 9	45·4	44·5	45·6	44·7	...	...	...	...	...	44·4
350	...	...	...	...	...	...	42·8	42·9	42·8	43·0	...	...
550	...	...	...	...	...	...	42·5	42·6	42·4	42·4	...	...

Date	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 3.
Time	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	10 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Portclair.
Wind	Calm.	Calm.	SSW. ½.	SW. 2.	SW. ½.	SW. ½.	Calm.	W. ½.	Calm.	NE. 0-½.	Calm.	SW. 3-4.
Air Temp.	57·5	59·5	66·5	67·5	..	67·5	68·5	68·9	63·5	62·1	62·0	..
Depth. Feet.												
0	52·5	54·8	54·1	53·7	54·0	54·1	54·3	54·3	54·9	52·6	54·9	54·1
25	52·5	53·1	52·8	52·8	52·9	52·6	52·5	52·5	52·5	52·3	52·7	...
50	52·3	52·7	52·5	52·4	52·2	52·0	51·9	51·9	52·1	51·9	52·0	52·8
75	52·1	52·0	52·5	...	52·0	51·5	50·4	51·0	52·0	51·6	51·5	...
100	51·5	51·8	51·8	50·1	49·9	49·5	49·1	49·8	50·4	50·2	51·0	49·9
125	49·6	49·6	49·4	48·5	48·1	47·8	47·1	48·7	49·9	50·0	49·8	...
150	48·0	47·9	48·1	46·8	46·0	46·0	45·7	46·9	49·0	49·1	47·5	47·3
175	46·0	45·8	46·5	45·5	45·1	45·0	45·0	45·2	46·8	46·8	46·0	...
200	45·0	45·2	45·2	44·1	43·9	43·8	43·8	44·3	45·3	45·2	45·0	44·0
225	44·1	44·0	43·4	43·8	43·2	43·2	43·7	43·7	44·3	44·1	44·0	...
350	...	...		...	...	...	...	...	...	...	...	42·5
550	...	...	...	...	...	...	...	...	...	...	...	42·0

Date	1904. Aug. 3.	1904. Aug. 3.	1904, Aug. 3.	1904. Aug. 3.	1904. Aug. 3.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.
Time	11 a.m.	12.15 p.m.	1.15 p.m.	2.30 p.m.	3.10 p.m.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Altsigh.	Inver-farigaig.	Temple Pier.	Abriachan	Aldourie.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2-3.	SW. 3-4.	SW. 1-2.	SW. 1-2.	SW. 1-2.	Calm.	Calm.	SW. 0-½.	SW. 2.	SW. 2.	SW. 3.	SW. 2.
Air Temp.	..	..	..	..	..	60·0	60·0	61·5	66·5	74·0	75·5	69·0
Depth. Feet.												
0	55·0	55·4	55·9	56·6	57·0	55·1	55·4	54·7	53·7	54·2	52·7	54·7
25	...	...	...	...	...	53·7	53·7	52·9	52·9	52·9	52·9	52·8
50	54·1	54·6	54·6	55·6	56·1	53·3	52·6	52·4	52·9	52·6	52·7	52·6
75	...	...	...	...	...	52·6	51·1	51·1	51·9	51·5	51·8	50·9
100	53·9	49·8	49·0	49·2	48·2	50·0	50·2	50·2	48·2	48·9	48·3	48·4
125	...	...	...	...	...	48·2	48·3	48·0	47·1	47·4	45·9	46·0
150	47·2	47·0	46·8	46·9	45·9	46·8	46·8	46·5	45·5	44·8	44·8	44·7
175	...	...	...	...	...	45·5	45·4	44·8	44·3	43·9	43·9	44·1
200	45·0	44·7	44·7	44·4	44·9	44·6	44·4	...	43·5	43·5	43·5	43·5
225	...	...	..	...	...	43·8	43·5	43·3	43·2	43·2	43·2	43·2
300	...	...	...	43·0	...	...	...	...	...	...	...	...
350	43·0	42·5	42·9	...	...	...	...	...	...	...	...	...
550	42·1	42·5	42·3	...	...	...	...	...	...	...	...	...

Date	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 4.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8.30 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2.	SW. 3.	SW. 2.	S. 0-½.	Calm.	NE. 0-½.	Calm.	Calm.	SW. ½.	SW. ½.	SW. 2.	SW. 3.
Air Temp.	70·5	68·0	..	..	..	..	..	..	..	59·5	61·5	58·5
Depth. Feet.												
0	53·9	54·1	53·9	54·6	54·9	55·1	55·2	55·1	56·1	55·2	54·8	54·0
25	52·8	52·9	52·6	53·1	53·2	53·6	53·5	54·2	53·8	53·7	53·8	53·7
50	52·5	52·6	52·4	52·3	52·5	52·4	52·1	53·4	53·6	53·5	53·4	53·0
75	51·1	52·1	51·9	51·9	51·9	51·6	51·9	51·5	53·1	52·9	52·5	51·2
100	49·8	50·0	50·0	50·2	51·0	51·0	50·2	50·2	50·0	50·0	49·8	49·0
125	45·3	47·2	47·2	47·5	48·0	48·9	48·2	48·0	47·8	47·0	47·1	46·4
150	44·5	45·0	45·1	45·3	45·8	47·5	47·8	45·8	45·6	45·6	45·5	45·8
175	43·9	44·2	44·2	44·5	45·2	46·8	47·4	45·3	44·8	44·9	45·0	44·8
200	43·5	43·7	43·8	44·0	44·5	46·0	45·0	44·6	44·0	43·9	44·1	44·1
225	43·3	43·3	43·7	43·8	44·0	45·2	44·9	44·2	43·7	43·7	43·8	43·9

Date	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 5.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	SW. 3.	Calm.	SW. ½.	Calm.	Calm.	Calm.	NE. 1.	NE. 2.	NE. 3.	NE. 2.	NE. 1.
Air Temp.	61·0	59·0	57·3	54·5	52·0	50·0	52·0	56·0	54·5	56·0	55·5	56·5
Depth. Feet.												
0	54·0	54·1	53·4	53·4	55·0	55·2	56·7	55·2	53·9	53·4	53·9	53·9
25	53·3	53·4	52·9	52·9	52·9	52·9	52·9	52·9	53·6	53·3	53·6	53·8
50	52·7	52·7	52·2	52·2	52·1	52·1	52·1	52·6	52·9	53·1	53·4	53·6
75	50·8	51·4	50·7	50·9	50·3	49·8	50·1	51·5	52·3	52·1	53·1	53·1
100	48·8	49·7	49·5	48·4	48·0	47·1	47·0	50·0	50·0	51·2	51·2	51·0
125	46·7	48·2	49·0	47·0	46·1	46·0	45·8	47·6	48·4	49·5	48·0	46·8
150	45·9	46·7	47·0	46·1	45·7	45·5	45·3	45·7	46·1	48·1	45·5	45·1
175	45·2	45·9	45·7	45·5	45·2	45·0	45·2	45·7	45·9	46·3	45·3	45·2
200	44·2	45·0	45·0	45·0	44·7	44·9	44·9	45·1	45·2	45·1	45·0	44·8
225	44·0	44·5	44·3	44·3	44·2	...	44·3	44·8	45·0	44·8	44·5	44·6

Date	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 6.	1904. Aug. 7.	1904. Aug. 7.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	10.30 a.m.	11.45 a.m.	1 p.m.	3.30 p.m.	4.45 p.m.	2 a.m.	4 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Abriachan	Urquhart.	Inver-farigaig.	Altsigh.	Port Clair.	Yacht.	Yacht.
Wind	Calm.	NE. 1.	NE. 1.	NE. 1–2.	Calm.	NE. 1.	NE. ½.	NE. ½.	NE. 0–½.	..	SW. ½.	Calm.
Air Temp.	56·0	57·0	57·5	57·0	..	59·0	60·0	60·0	60·0	59·0	..	..
Depth. Feet.												
0	54·1	55·5	54·1	54·1	56·8	57·0	57·0	55·9	55·2	55·7	56·6	56·4
25	53·9	53·6	53·9	53·9	54·6	...	...	...	...	...	54·3	54·5
50	53·9	53·4	53·9	53·9	54·1	56·3	56·8	55·3	55·0	54·0	54·3	54·4
75	52·6	53·6	53·9	53·9	54·1	...	...	...	...	...	54·2	54·2
100	51·9	50·5	53·8	53·9	54·0	49·5	51·0	50·2	50·5	52·0	54·0	54·0
125	47·8	46·2	49·4	49·6	49·9	...	...	...	...	...	49·8	49·6
150	45·1	45·0	47·5	47·6	49·0	47·1	46·7	47·0	47·0	47·3	48·7	48·2
175	45·0	44·9	45·7	45·8	45·3	...	...	...	...	...	46·6	46·8
200	44·8	44·8	45·1	45·3	44·8	44·4	44·5	45·4	44·9	45·4	45·4	45·7
225	44·7	44·0	44·4	44·8	44·5	...	...	...	..	...	44·3	45·0
300	...	...	. .	...	...	43·0	43·1	43·3	43·1	43·7	...	...
400	...	...	...	...	...	42·7	42·8	42·8	42·8	42·8	...	...
600	...	...	...	...	...	...	...	...	...	42·7	...	...
700	...	...	...	...	...	...	42·3	42·3	42·3	...	...	...

Date	1904. Aug. 7.	1904. Aug. 7.	1904. Aug. 7.	1904. Aug. 7.	1904. Aug. 7.	1904. Aug. 7.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.
Time	10.15 a.m.	12 noon.	3 p.m.	6.15 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8.5 a.m.	10 a.m.	12 noon.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SW. 1.	SW. 1–2.	SW. 1.	SW. 0–1.	Calm.	Calm.	W. ½.	W. 0–½.	SW. 1.	SW. 1.	SW. 1.
Air Temp.	60·0	58·0	62·0	60·0	..	..	..	50·0	52·0	63·5	64·5	65·0
Depth. Feet.												
0	57·2	56·1	54·1	56·7	56·8	58·1	57·1	57·0	56·7	57·1	56·6	55·0
25	54·6	54·8	54·1	54·2	54·4	54·4	54·4	54·3	54·3	54·4	54·3	54·4
50	54·4	54·4	54·1	54·2	54·0	54·4	54·2	54·2	54·2	54·3	51·8	51·8
75	54·4	54·0	54·2	54·0	50·5	50·2	49·8	49·0	48·9	48·4	47·8	47·7
100	54·3	50·8	49·3	48·5	48·0	47·7	47·3	46·7	46·0	46·0	45·8	46·0
125	48·8	48·3	47·6	46·2	45·6	45·6	45·7	45·6	45·5	45·3	45·5	45·2
150	47·0	46·9	46·2	45·8	45·8	45·3	45·3	45·2	45·4	44·9	45·0	44·9
175	46·2	46·2	45·2	45·6	45·1	45·0	45·0	45·1	45·1	44·3	44·6	44·7
200	45·7	45·2	45·2	45·1	44·3	45·0	44·6	44·7	44·7	44·0	44·0	44·1
225	45·1	44·9	45·1	44·9	44·1	44·1	44 0	44·2	43·7	43·7	43·8	43·8

Date	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 8.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.
Time	2 p.m.	4 p.m.	6 p.m.	8 p.m	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a m.	12 noon.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 2.	SSW. 2.	Calm.	SW. 1.	Calm.	Calm.	Calm.	SW. 0–½.	Calm.	Calm.	Calm.	SSW. ½.
Air Temp.	65·0	63·0	61·0	59·0	58·0	..	57·0	55·5	58·5	61·0	65·0	72·0
Depth. Feet.												
0	55·0	59·9	55·1	55·7	56·8	56·2	56·0	55·9	58·0	57·0	56·0	58·9
25	54·1	54·0	54·0	54·0	55·3	55·3	54·9	54·8	54·2	54·3	54·0	54·0
50	51·0	50·9	50·2	50·5	54·0	54·0	54·1	54·0	54·0	54·0	53·8	54·0
75	47·8	48·3	47·9	48·3	49·0	50·8	51·0	51·5	53·8	53·8	53·8	53·8
100	45·9	46·0	45·8	45·7	47·2	49·0	48·8	49·0	51·0	52·4	52·5	52·7
125	45·4	45·2	45·1	45·0	45·5	48·0	47·5	48·0	49·5	51·9	50·4	51·0
150	45·0	45·0	44·8	45·0	45·2	47·1	46·1	45·2	47·5	47·6	47·9	48·1
175	44·6	44·7	44·2	44·2	45·0	45·3	45·0	45·0	47·1	46·3	46·9	46·6
200	44·0	44·0	43·7	43·9	44·4	44·5	44·2	44·3	46·0	45·8	45·8	46·3
225	43·8	43·7	43·5	43·6	44·0	44·0	43·6	43·8	44·2	45·2	45·0	45·3

Date	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 9.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug 10.	1904. Aug. 10.	1904. Aug. 10.
Time	2 p m.	4 p.m.	6 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10.15 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. ½.	SW. 0–1.	NE. 1.	Calm.	Calm.	Calm.	SW. ½.	Calm.	Calm.	SW. 1.	SW. 1.	W. 1.
Air Temp.	64·5	65·5	..	56·0	..	53·0	52·5	52·0	58·5	63·8	64·5	62·8
Depth. Feet.												
0	56·3	56·0	58·5	59·0	59·3	59·0	57·8	58·0	57·2	57·5	58·0	56·5
25	54·1	54·0	54·0	54·0	54·1	54·0	54·0	54·2	54·5	54·8	55·0	54·0
50	54·0	54·0	53·9	53·8	53·6	53·8	53·8	53·8	53·3	53·9	53·8	53·9
75	53·5	53·6	53·7	53·5	53·4	53·2	53·3	52·3	50·2	52·0	50·8	51·5
100	53·2	52·2	51·8	51·5	51·8	50·3	49·1	48·9	48·5	48·0	48·2	49·8
125	50·0	49·8	49·1	49·4	49·5	49·1	47·8	47·5	47·8	46·8	47·0	48·0
150	47·8	48·5	47·1	47·0	47·0	46·7	46·7	46·4	47·6	46·3	46·3	47·1
175	46·8	47·0	46·5	46·7	46·6	46·5	46·5	46·3	47·5	46·0	46·0	46·2
200	46·1	46·2	46·0	46·0	45·8	45·7	45·7	45·7	45·6	45·8	45·8	45·8
225	45·3	45·3	45·4	45·3	45·2	45·2	45·0	45·3	45·2	45·6	45·5	45·5

Date	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 10.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.
Time	4 p.m.	6 p.m.	8 p.m.	10.10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	W. ½.	NE. ½.	NE. ½.	SW. ½.	SW. 0–½.	SW. ½.	SW. ½.	Calm.	NE. 1.	NE. ½.	Calm.
Air Temp.	64·5	63·8	59·5	55·0	51·0	50·5	48·0	48·0	53·0	57·5	62·0	62·2
Depth. Feet.												
0	56·8	55·8	56·4	58·5	58·0	57·1	57·2	57·0	56·8	57·2	57·9	58·5
25	54·5	54·0	54·0	54·0	54·1	54·0	54·0	54·1	54·5	54·5	55·0	55·5
50	53·6	53·5	53·6	53·8	53·7	53·5	53·7	54·0	53·3	53·8	54·2	54·8
75	50 8	51·1	50·1	50·5	50·5	50·2	49·0	49·3	49·5	49·9	54·0	54·0
100	49·0	49·8	48·8	48·6	48·2	48·0	48·0	48·0	48·0	47·8	52·0	52·2
125	48·0	47·3	47·8	47·5	47·6	47·2	46·3	46·3	46·0	46·5	50·2	51·8
150	46·8	46·8	47·0	46·3	46·2	46·1	45·6	45·5	45·2	45·6	49·0	50·0
175	46·2	46·2	46·7	46·2	46·0	45·9	44·8	44·8	44·7	45·0	48·9	48·0
200	46·0	45·5	45·3	46·3	45·3	44·6	44·1	44·1	44·0	44·2	45·8	46·8
225	45·6	45·0	45·0	44·7	44·5	44·3	43·8	43·8	43·5	43·7	45·0	46·4

Date	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 11.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	Calm.	Calm.	NE. ½.	Calm.	Calm.	SW. ½.	SW. ½.	WSW. ½.	SSW. ½.	SSW. ½.	SW. 1.
Air Temp.	57·0	57·8	56·8	53·5	54·0	51·8	49·0	48·5	51·5	56·8	62·0	60·5
Depth. Feet.												
0	57·0	57·2	58·5	58·0	57·5	57·0	56·1	57·2	56·8	56·8	57·1	56·8
25	55·6	55·4	55·9	56·0	56·0	56·0	55·8	56·0	55·9	55·9	56·0	55·7
50	55·4	55·0	55·0	55·1	55·0	54·8	54·6	53·8	54·3	54·0	54·8	54·8
75	53·2	53·2	54·1	53·7	53·1	50·1	53·4	53·3	53·8	53·0	54·0	54·0
100	52·4	52·0	50·0	49·8	49·4	49·3	...	49·8	50·0	49·5	49·7	50·0
125	50·1	48·8	49·0	49·1	48·2	48·1	48·8	48·9	48·4	49·5	48·1	48·1
150	49·3	48·0	48·0	47·9	47·2	47·0	47·6	47·9	47·3	47·2	46·2	46·0
175	46·5	46·5	47·2	46·3	45·8	45·6	45·7	46·1	45·6	45·5	45·2	45·2
200	44·8	46·0	46·3	45·8	44·4	44·2	45·1	44·8	44·5	44·8	44·0	44·0
225	43·9	43·5	45·1	44·4	43·8	44·0	44·0	44·0	43·9	43·5	43·7	43·7

Date	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 12.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	W. ½.	Calm.	Calm.	Calm.	Calm.	Calm.	NE. 1.	NE. 1.	..	W.	W.
Air Temp.	63·5	66·0	59·8	57·0	57·5	55·8	55·0	54·8	55·0	52·5	58·2	60·0
Depth. Feet.												
0	56·2	55·9	57·8	57·0	58·2	56·9	56·5	56·5	56·1	56·0	58·0	55·4
25	55·4	55·4	55·1	55·0	55·4	55·5	55·0	55·0	55·9	56·0	56·0	55·5
50	54·3	54·0	53·8	54·2	54·3	54·0	53·8	54·1	53 9	53·5	54·2	54·0
75	53 2	49·8	50·1	50·3	51·0	50·2	50·3	53·0	51·8	53·8	52·0	50 0
100	49·0	48·3	48·2	48·0	48·6	48·5	48·4	48·8	48·2	48·0	48·6	47·8
125	48·0	46·8	46·7	47·1	47·3	46·8	46·6	47·2	46·3	45·8	46·8	46·0
150	46·0	45 5	45·3	45·8	46·1	46·0	45·1	45·0	45·6	44·8	45·8	45·3
175	45·0	44·5	44·8	44·8	44·8	44·5	44·5	44·3	44·8	44·0	44·8	44·2
200	43·9	44·0	44·2	44·1	44·2	44·0	43·9	43·7	43·8	43·5	43·5	44·0
225	43·3	43·4	43·9	43·7	43·8	43·6	43·4	43·1	43·4	43·0	43·0	43·2

Date	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 13.	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 14.
Time	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	12 noon.	3 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 3–4.	NW.	SW. ½.	SW. 1.	SW. 1.	NE. ¼.	NE. ¼.	SW. 1–2.	SW. 2–3.	SW. 2–3.	SW. 1–2.	Calm.
Air Temp.	59·5	59·0	58·0	59·0	58·5	..	58·0	..	61·0	59·0	56·2	55·0
Depth. Feet.												
0	54·8	54·3	55·7	55·5	55·0	56·7	55·1	56·5	58·2	51·9	51·1	52·1
25	54·8	54·3	54·0	54·6	53·8	54·0	54·0	54·1	51·5	50·8	49·6	49·5
50	53·4	54·5	53·5	53·2	53·5	53·6	54·0	53·7	50·4	49·1	48·8	47·0
75	50·7	54·5	49·5	51·0	51·2	50·7	52·0	52·0	49·2	48·1	47·6	47·0
100	48·8	48·1	48·3	49·5	50·0	50·1	50·2	51·0	47·8	47·2	46·7	46·4
125	47·8	46·6	46·7	48·1	48·8	48·5	48·7	48·3	45·9	45·8	45·9	45·8
150	46·0	45·8	44·8	47·1	48·0	47·5	47·9	46·8	45·1	44·8	45·2	45·3
175	45·5	45·5	45·0	46·1	45·0	45·6	45·5	45·0	44·9	44·8	44·6	45·0
200	44·8	44·2	44·3	44·7	45·0	45·2	44·8	44·6	43·9	44·1	44·1	44·3
225	44·0	43·5	44·0	44·0	44·0	44·0	44·0	43·7	43·2	43·6	43·5	43·5

Date	1904. Aug. 14.	1904. Aug. 14.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 15.
Time	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 1.	NE. 1.	NE. 4.	NE. 3.	NE. 3.	Calm.	W.	NE.	NE.	E.	Calm.	Calm.
Air Temp.	54·5	54·2	50·0	55·5	55·5	55 5	58·0	58·8	55·2	55·5	54·4	52·0
Depth. Feet.												
0	53·4	53·5	52·2	53·0	54·5	55·2	56·4	56·2	54·5	56·0	54·0	56·0
25	50·0	50·8	51·1	52·2	52·0	52·3	52·5	52·3	53·3	54·5	54·0	54·9
50	48·9	49·4	50·2	52·0	51·9	52·2	52·1	52·5	53·5	53·8	...	54·6
75	47·4	49·0	49·8	51·3	51·0	52·0	52·0	52·0	56·0	53·2	54·0	53·8
100	46·8	48·0	49·0	49·6	49·8	50·1	49·0	48·8	52·8	53·6	53·5	53·4
125	45·9	46·5	47·6	49·3	49·0	48·3	47·8	47·3	52·8	51·8	52·8	53·0
150	45·4	45·6	47·3	47·8	47·2	47·4	47·1	46·0	51·8	50·8	51·8	49·8
175	45·0	45·2	46·0	46·3	46·5	46·8	46·0	46·0	51·0	49·0	51·0	49·0
200	44·4	44·5	45·5	45·5	45·8	45·5	45·0	45·0	48·0	48·9	48·0	48·9
225	43·9	43·8	45·0	45·2	45·4	45·0	44·2	44·0	48·0	46·8	46·8	47·4

Date	1904. Aug. 15.	1904. Aug. 15.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 16.
Time	10 p.m.	12 midnight.	2 a.m.	4 p.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	WSW. 1.	Calm.	SW. ½.	SW. 1–2.	SW. 1.	..	SW. 2.	SW. 1–4.	SW. 1.	SW. 2.	SW. 1.	SW. 1.
Air Temp.	51·0	51·0	51·0	52·0	54·5	54·3	..	60·0	60·5	60·0	50·8	53·5
Depth. Feet.												
0	55·8	55·3	54·8	54·7	54·7	54·0	54·1	54·1	54·1	53·5	55·2	56·0
25	54·2	54·7	54 8	54·3	54·4	54·0	53·9	53·8	54·0	52·4	53·2	53·3
50	53·9	54·0	53·7	53·8	53·8	53·9	53·8	53·2	53·0	50·3	50·0	49·7
75	53·5	53·7	53·7	53·7	53·8	54·8	53·0	50·1	50·0	49·0	48·3	48·5
100	53·4	53·6	53·8	53·5	53·5	...	49·8	48·8	48·6	47·6	46·5	46·3
125	53·0	53·3	51·7	50·8	50·9	49·2	48·3	46·3	46·8	45·9	45·6	45·6
150	49·8	49·9	50·3	49·1	49·0	47·8	46·9	45·3	45·6	44·8	44·8	44·6
175	49·1	49·6	49·0	47·4	47·8	46·0	45·5	45·0	45·3	44·3	44·4	44·3
200	48·3	48·1	48·0	45·9	46·3	45·1	44·6	44·0	44·8	44·0	43·9	43·7
225	49·2	46·9	47·0	45·0	45·4	44·5	44·2	43·5	44·0	43·2	43·5	43·3

Date	1904. Aug. 16.	1904. Aug. 16.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 17.
Time	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. ½.	Calm.	Calm.	E. ½.	NE. 1.	NE. 1.	NE. 2.	NE. 2.	NE. 2.	NE. 1–2.	NE. 2.	NE. 2–3.
Air Temp.	53·0	51·3	45·0	49·5	50·5	59·8	60·1	60·0	59·5	62·0	58·5	55·5
Depth. Feet.												
0	56·1	55·8	56·0	55·0	55·1	55·0	55·5	56·3	56·8	56·1	56·0	55·7
25	53·2	53·2	53·5	53·7	54·0	54·5	54·4	54·4	54·5	54·8	54·3	54·4
50	49·5	49·0	50·0	49·9	50·1	51·2	51·4	52·2	53·0	54·2	54·2	54·2
75	47·8	47·3	47·8	47·2	48·3	49·0	48·9	49·1	49·0	54·0	54·2	54·0
100	45·8	45·6	45·9	45·1	45·0	45·9	46·1	47·0	46·6	54·2	53·8	53·8
125	44·8	44·9	44·7	44·1	44·2	44·6	44·3	44·3	44·3	53·6	53·6	53·8
150	44·3	44·1	44·0	43·8	43·7	44·0	43·8	43·8	43·7	53·7	53·2	53·6
175	43·9	44·0	43·9	43·6	43·6	43·5	43·5	43·5	43·3	50·0	52·0	53·2
200	43·7	43·6	43·3	43·4	43·4	43·2	43·2	43·2	43·1	44·0	48·8	52·2
225	43·5	43·6	43·0	...	43·0	43·0	43·1	43·1	43·0	43·1	44·2	47·8

Date	1904. Aug. 17.	1904. Aug. 17.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 18.
Time	10.15 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SE. 1.	NE. 1–2.	NE. 1.	SW. ½.	SW. ½.	Calm.	Calm.	NE. ½.	SW. ½–3.	SW. ½–1.	Calm.	Calm.
Air Temp.	52·5	54·8	52·5	48·0	46·8	59·0	..	..	65·4	54·5	53·2	52·0
Depth. Feet.												
0	55·4	55·3	55·2	55·0	55·8	56·2	58·8	58·0	57·8	54·7	56·5	56·7
25	54·1	54·1	54·0	54·0	54·0	54·0	54·0	54·1	54·0	54·0	54·0	54·0
50	54·0	53·9	53·8	54·0	53·9	54·0	54·0	53·9	54·0	53·9	54·0	54·0
75	54·0	54·0	53·8	53·8	53·9	54·0	54·0	53·9	53·8	53·8	53·9	53·8
100	53·7	53·7	53·8	53·8	53·8	53·7	53·8	53·7	53·5	51·8	53·3	51·1
125	53·5	53·2	53·4	53·5	53·6	53·6	53·7	50·7	51·0	49·9	50 0	48·8
150	52·8	52·9	52·8	51·6	51·6	51·4	50·8	48·3	49·0	47·8	46·8	46·3
175	52·1	52·2	52·0	51·2	51·2	49·7	48·1	46·2	48·0	46·7	46·3	44·7
200	51·7	51·1	51·0	48·0	46·8	46·1	45·9	44·8	45·0	45·5	45·0	44·3
225	51·5	50·4	48·4	46·6	44·9	44·5	45·0	44·4	44·4	44·7	44·2	43·8

Date	1904. Aug. 18.	1904. Aug. 18.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 19.
Time	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. ½.	S. ½.	S. 3.	NE. 2.	NE. 1.	NE. 1–2.	NE. 1.	Calm.	ENE. ¼.	Calm.	Calm.	NE. 1.
Air Temp.	47·0	48·5	47·0	48·0	46·0	48·3	52·5	58·5	59·3	53·3	56·0	49·5
Depth. Feet.												
0	55·9	55·5	55·8	55·5	55·0	55·7	55·6	56·6	56·9	56·8	56·9	56·5
25	54·0	54·0	54·3	54·6	54·4	54·5	54·6	54·7	54·8	55·0	54·9	55·1
50	54·0	54·0	54·0	53·9	54·0	54·0	54·2	54·5	54·7	54·9	54·8	54·9
75	53·7	53·0	53·5	54·0	53·9	54·0	54·0	54·4	54·4	54·5	54·7	54·9
100	51·7	50·2	50·6	52·0	53·3	53·8	50·3	48·6	48·5	48·5	49·1	54·7
125	48·8	48·6	48·8	47·7	45·9	46·2	45·8	45·7	45·1	46·1	46·1	48·9
150	46·8	46·3	46·6	45·8	44·8	44·8	44·6	44·6	44·2	44·7	45·1	45·2
175	45·0	44·8	44·9	44·3	44·4	44·8	44·1	44·2	44·0	44·2	44·5	44·9
200	44·3	44·4	44·0	44·2	43·7	44·0	43·9	44·0	43·9	43·7	44·0	44·5
225	43·2	43·4	43·5	44·0	43·4	43·8	43·6	43·6	43·3	43·3	43·4	43·3

Date	1904. Aug. 19.	1904. Aug. 19.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 20.
Time	10 p.m.	12 midnight.	2 a.m.	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	Calm.	SW. ½.	Calm.	Calm.	Calm.	NNE. ½.	WSW. 1.	NE. 1.	NE. 1.	SW. 1.	S. 1–2.
Air Temp.	48·0	47·8	46·5	47·3	48·0	53·0	..	57·5	57·5	61·5	59·0	55·5
Depth. Feet.												
0	55·6	56·0	56·0	56·0	56·0	55·3	55·6	57·0	57·4	57·6	58·0	57·0
10	...	...	...	...	...	...	...	55·5	55·3	56·5	56·5	55·5
25	55·0	55·1	55·1	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0
50	54·9	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0
75	54·8	55·0	54·9	55·0	55·0	55·0	55·0	55·0	55·0	54·9	54·9	54·9
100	55·0	54·9	54·8	54·8	54·8	54·8	51·8	51·5	50·0	50·0	51·0	50·6
125	55·0	54·8	54·7	54·7	48·8	47·8	47·0	47·7	48·0	47·6	47·7	47·2
150	53·5	54·2	53·8	54·0	46·6	45·5	44·1	45·3	45·1	45·0	46·0	46·2
175	45·9	54·0	53·5	53·0	45·0	45·0	44·7	44·5	45·0	44·7	45·1	45·0
200	45·0	47·2	46·8	45·5	44·2	44·8	43·8	44·1	44·1	43·8	44·5	44·5
225	44·2	44·2	44·2	44·0	44·0	43·8	43·5	43·7	43·7	43·4	43·7	43·8

Date	1904. Aug. 20.	1904. Aug. 20.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 21.	1904. Aug. 22.
Time	10 p.m.	12 midnight.	2 a.m.	6 a.m.	9 a.m.	12 noon.	3 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	S. ¼.	Calm.	Calm.	SW. ¼.	SW. 1–2.	S. 2–3.	SW. 1.	Calm.	Calm.	Calm.	Calm.	Calm.
Air Temp.	50·5	47·0	46·5	48·0	59·0	56·5	56·5	53·5	51·5	49·0	50·0	48·5
Depth. Feet.												
0	56·7	56·7	56·7	56·0	55·7	55·1	55·1	58·0	57·0	56·0	55·9	55·7
10	55·2	55·3	55·3	55·9	55·7	55·1	55·2	55·0	55·1	55·0	55·0	55·0
25	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	55·0	54·8	54·9
50	55·0	54·8	54·9	54·9	54·5	53·0	52·4	53·2	54·0	52·2	52·0	52·8
75	55·0	48·6	54·6	49·0	53·9	48·0	48·8	48·0	49·1	49·7	51·0	48·7
100	49·9	46·1	48·6	46 8	46·3	46·7	46·5	47·0	47·6	47·8	47·8	48·0
125	46·8	45·5	46·1	45·9	45·7	46·2	45·8	46·6	46·6	...	47·0	47·0
150	45·8	45·5	45·5	44·8	45·3	45·8	45·5	45·8	46·0	45·9	46·7	46·8
175	45·2	44·8	44·3	44·3	45·0	45·6	45·0	45·3	45·3	45·8	46·0	45·6
200	44·6	44·1	43·6	43·8	44·7	44·8	44·7	44·9	44·8	44·9	45·1	45·2
225	43·8	43·6	43·4	43·5	44·0	44·5	44·1	44·3	44·3	44·5	44·2	44·3

Date	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 22.	1904. Aug. 23.	1904. Aug. 23.
Time	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12.30 a.m.	2 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	S. ½.	SW. ½.	Calm.	Calm.	NE. 1.	NE. 1–2.	NE. 4–5.	NE. 3–4.	NE. 1.	NE. 1.	NE. 2.	NE. 1.
Air Temp.	47·0	48·5	51·5	58·0	57·5	59·5	58·0	56·0	57·5	57·0	51·5	..
Depth. Feet.												
0	56·0	56·0	55·9	56·4	57·4	58·8	56·8	56·9	...	56·3	56·7	56·7
10	55·0	55·7	55·3	...	55·8	56·8	56·9	56·8	...	..	56·7	56·1
25	54·7	55·0	54·8	54·5	55·0	54·7	56·5	56·1	55·9	53·8	56·0	56·0
50	53·4	54·1	53·7	52·0	52·9	54 1	54·3	55·7	55·5	52·5	55·6	55·5
75	50·3	50·8	50·7	50·8	50·8	51·9	52·0	56·2	54·0	52·0	55·0	54·2
100	48·8	49·7	50·0	48·9	50·0	50·6	51·6	51·9	51·0	50·2	51·9	51·7
125	47·8	48·5	48·8	48·8	48·9	50·1	50·7	51·2	50·9	...	51·2	51·3
150	47·6	47·8	47·9	48·1	48·3	49·3	50·1	50·8	49·5	49·9	...	50·0
175	46·6	46·7	47·2	47·8	47·7	48·9	49·2	49·0	48·9	49·8	...	48·5
200	45·7	46·4	45·8	45·7	45·7	46·8	47·8	48 9	48·2	49·5	...	47·3
225	44·7	45·4	44·5	45·0	44·9	46·0	46·5	47·4	45·2	45·3	...	45·8

Date	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 23.	1904. Aug. 24.
Time	4 a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.	12 midnight.	2 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SE. ½.	Calm.	NE. 1.	NE. 1.	NE. 1.	NE. ½–1.	N. ½.	SE. 1.	Calm.	Calm.	Calm.
Air Temp.	51·3	51·0	55·5	56·0	58·0	57·5	58·2	57·0	53·0	52·0	51·5	50·5
Depth. Feet.												
0	56·5	56 5	56·3	57·0	57·0	57·0	57·2	57·2	56·9	56·9	57·0	56·7
10	56·1	55·9	...	55·9	...	57·0	...	56·5	56·3	56·5	57·0	56·2
25	56·0	55·8	56·0	55·7	55·8	55·8	55·8	55·6	55·7	56·0	55·8	55·8
50	55 4	55·4	55·2	55·6	55·6	55·6	55·2	55·2	55·1	55·1	55·2	54·9
75	53·0	54·2	53·8	54·3	54·2	54·0	54·1	53·1	53·0	52·3	52·3	51·7
100	51·7	54·4	52·0	52·0	52·3	52·2	52·0	51·5	51·2	50·7	49·2	49·2
125	51·3	52·4	51·7		51·1	51·0	50·9	49·7	48·7	48·3	47·7	46·8
135	...	...	...	50·7	...	...	...	...	...	...	...	...
150	50·1	49·7	49·0	49·6	49·0	49·1	48·2	47·3	46·6	45·9	47·1	45·2
175	48·4	47·7	47·8	47·5	47·2	47 3	46·8	44·9	44·6	44·6	44·9	44·5
200	47·1	45·9	46·0	46·1	45·5	45·5	45·6	44·8	44·4	44·2	44·2	44·2
225	45·6	45·1	45·5	45·0	44·3	44·1	44·3	44·2	43·9	44·0	44·0	43·7

Date	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.	1904. Aug. 24.
Time	4. a.m.	6 a.m.	8 a.m.	10 a.m.	12 noon.	2 p.m.	4 p.m.	6 p.m.	8 p.m.	10 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	Calm.	NE. 1.	NE. 1.	NE. 1.	NE. 1.	NE 1.	NE. ½.	Calm.	Calm.
Air Temp.	51·0	50·5	52·5	57·5	61·3	64·0	..	57·5	57·0	..
Depth. Feet.										
0	56·3	56·8	56·3	57·0	56·8	57·0	57·5	57·5	57·2	57·0
10	56·0	56·2	56·3	56·4	56·7	56·9	57·0	...	...	...
25	55·8	55·6	55·8	55·6	55·6	56·7	56·5	56·1	56·2	55·8
50	55·0	54·6	54·3	54·9	55·0	55·1	55·5	55·4	55·5	53·5
75	51·8	51·6	51·6	51·7	51·8	52·6	53·1	53·5	53·0	51·7
100	48·8	49·0	48·6	48·6	49·4	51·0	51·0	51·8	52·2	50·5
125	46·8	47·0	46·6	46·7	46·8	47·7	48·0	49·0	50·0	49·9
150	45·0	45·2	45·2	45·2	45·2	45·6	45·7	47·8	48·5	48·2
175	44·7	44·8	44·8	44·5	44·1	44·8	44·5	45·0	46·7	46·5
200	44·0	44·0	44·0	44·0	43·9	44·0	44·0	44·2	44·2	46·0
225	43·3	43·7	43·6	43·5	43·4	43·6	43·7	43·9	43·8	44·1

Date	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 8.	1904. Sept. 9.
Time	6 a.m.	10 a.m.	12 noon.	2 p.m.	6 p.m.	8 a.m.	1 p.m.	6 p.m.	6 a.m.	noon.	6 p.m.	6 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.	Dores.	Yacht.
Wind	Variable.	SW. 2-3.	SW. 2.	SSW. 3-4.	SW. 2.	SW. 0-2.	SW. 5.	SW. 5.	NE. ¼.	SW. 2.	SW. 1.	SW. 2.
Air Temp.	50·5	55·5	57·3	56·5	55·6	55·3	56·0	56·5	..	..		48·0
Depth. Feet.												
0	54·0	54·2	53·7	53·7	54·0	55·2	55·2	54·8	55·9	55·8	55·8	52·9
10	54·0	54·0	...	53·7	54·0	...	...	...	...	...	...	52·9
25	53·8	53·5	53·0	53·7	53·3	...	...	...	...	...	...	52·9
50	53·3	53·0	53·0	53·0	52·8	55·0	54·8	54·8	55·9	55·8	55·8	51·7
75	53·0	52·9	...	52·9	52·6	...	...	...	...	...	...	50·0
100	52·7	52·5	52·5	51·8	52·2	49·6	51·5	54·3	55·5	55·4	54·7	48·2
125	52·7	51·0	51·5	50·6	51·0	47·2	48·6	52·5	48·0	48·0	47·8	46·8
150	51·5	48·8	50·0	47·9	49·6	45·1	46·9	48·5	45·5	45·8	46·2	44·8
175	49·6	47·2	48·0	45·9	47·6	45·0	46·1	47·2	44·4	44·8	45·5	44·2
200	48·0	46·0	46·5	45·0	46·7	44·7	45·0	46·0	44·1	44·2	45·0	43·6
225	46·3	45·0	44·4	44·4	45·7	44·6	44·5	45·0	43·7	43·7	44·3	43·3
250	44·8	44·0	43·7	43·7	44·0	43·9	43·8	44·4	43·2	43·2	44·3	43·2
300	...	...	...	...	...	43·3	43·5	43·8	43·0	43·0	43·7	...
400	...	...	...	...	...	42·8	42·8	43·1	...	...	...	...
500	...	...	...	...	...	42·6	42·6	42·8	...	...	...	...
700	...	...	...	...	...	...	42·5	...	...	...	...	...

Date	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 9.	1904. Sept. 10.	1904. Sept. 10.
Time	10 a.m.	12 noon.	2 p.m.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6·30 a.m.	10 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.	Dores.	Yacht.	Yacht.
Wind	SW. 2-3.	SW. 3-4.	SW. 1.	SW. 2.	SWW. 3.	SWW. 4.	SW. 3.	SW. 3.	SW. 3-4.	SW. 1.	Variable.	W. 1-2.
Air Temp.	51·0	52·1	52·0	53·5	50·0	50·1	54·0	..	..	..	51·0	59·7
Depth. Feet.												
0	53·0	52·8	52·0	52·5	54·5	54·2	54·1	55·5	55·7	55·7	52·1	52·7
10	53·0	52·6	52·0	52·4	...	...	...	...	...	...	52·0	52·5
25	52·7	51·8	51·0	50·5	54·2	54·5	54·0	...	...	...	51·9	51·8
50	50·0	49·2	...	47·6	...	54·2	53·3	55·5	55·5	55·6	51·4	51·3
75	47·7	47·3	46·8	46·1	...	...	...	...	...	...	50·6	51·2
100	46·0	45·5	45·5	44·9	44·8	54·6	48·0	55·5	55·5	55·5	50·6	50·7
125	44·5	44·7	44·4	44·3	45·2	43·6	47·2	55·6	...	55·5	50·1	49·9
150	44·0	43·9	43·9	43·7	44·3	43·0	46·4	55·5	55·5	55·4	49·3	49·2
175	43·5	43·3	43·4	43·3	43·8	43·0	45·1	52·0	54·6	55·0	48·0	48·8
200	43·2	43·2	43·1	43·2	43·6	43·2	44·3	45·7	46·6	46·2	48·0	47·0
225	43·0	43·1	43·0	...	43·3	43·4	44·2	44·8	...	45·7	47·8	44·6
250	43·0	43·0	43·0	43·0	43·5	43·3	43·7	44·5	45·5	45·1	44·0	44·0
300	...	...	...	...	43·0	43·2	43·2	43·9	...	44·0	...	...
400	...	...	...	...	42·8	43·0	42·8	...	...	...	...	...
500	...	...	...	...	42·5	42·8	42·6	...	...	..	...	...
650	...	...	...	...	...	42·3	...	...	...	...	...	...

Date	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 10.	1904. Sept. 11.	1904. Sept. 11.	1904. Sept. 11.
Time	12 noon.	2 p.m.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	12 noon.	6 a.m.	12 noon.
Position	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.	Dores.	Yacht.	Dores.	Dores.
Wind	W. 1–3.	W. 1–2.	W. ½.	W. 2.	WNW. 2.	NNE.	SW. 1.	SW.&NW. squalls.	W. & N.	NE. 3.	SW. 1.	N. ½.
Air Temp.	62·9	58·5	54·5	53·0	57·1	54·8	..	..	..	54·2	..	..
Depth. Feet.												
0	52·8	53·0	53·0	54·5	55·1	55·0	55·5	55·7	55·7	53·8	55·3	56·3
10	52·7	53·0	53·0	...	...	...	...	...	...	53·5	...	...
25	52·4	52·7	52·0	54·3	54·8	54·3	...	...	...	53·5	...	55·3
50	52·0	52·4	52·6	54·2	54·6	54·3	...	55·4	55·3	52·7	55·4	55·2
75	51·8	52·2	52·3	...	...	...	...	...	...	52·6	55·2	...
100	51·6	52·0	52·2	53·9	51·8	47·4	55·5	55·3	54·9	52·2	48·2	55·1
125	51·4	51·9	51·9	48·2	48·9	47·6	55·3	51·6	47·2	52·1	46·0	55·0
150	51·3	51·9	51·8	47·6	46·8	46·0	47·3	46·6	45·8	50·5	45·2	49·8
175	51·0	51·5	50·1	46·5	45·1	44·8	45·9	45·5	45·0	47·6	44·2	47·0
200	50·0	49·8	48·9	44·5	44·6	44·4	45·5	45·4	44·6	45·5	43·4	46·2
225	49·4	48·6	45·7	44·1	43·8	44·0	45·1	44·8	44·0	44·5	43·0	45·0
250	48·6	47·2	45·0	43·8	...	43·6	44·1	44·5	43·5	44·0(240)	42·9	44·0
300	...	...	...	44·2	43·2	43·2	43·0	43·0	42·9	...	42·6	43·0
400	...	...	...	42·9	42·9	43·0	...	...	...	...	...	...
500	...	...	...	42·8	42·6	42·3	...	...	...	...	...	...
700	...	...	...	...	42·5	...	...	...	...	...	...	...

Date	1904. Sept. 11.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.	1904. Sept. 12.
Time	6 p.m.	6 a.m.	10 a.m.	12 noon.	2 p.m.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.
Position	Dores.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.	Dores.
Wind	NE. 1–2.	Calm.	Variable 1–3.	SE. 3–4.	SE. 1–4.	SW. 1–3.	Calm.	SW. 1–3.	WSW. 2.	Calm.	W. 1.	S. ½–1.
Air Temp.	..	48·0	55·0	56·3	60·5	52·2	50·0	56·8	53·2	..	..	..
Depth. Feet.												
0	55·4	53·6	53·8	53·8	54·4	54·0	55·0	55·0	54·8	55·1	55·1	55·3
10	...	53·7	53·8	53·8	54·2	54·0	...	...	...	...	...	...
25	...	53·6	53·7	53·7	53·8	53·9	54·5	54·5	54·8	...	...	...
50	55·2	53·5	53·4	53·6	53·6	53·9	54·2	54·2	54·0	55·1	55·2	54·6
75	...	53·4	53·4	53·3	53·6	53·3	...	...	...	55·4	54·7	53·2
100	55·0	53·2	53·4	53·3	53·5	53·2	52·9	52·6	51·8	53·9	53·3	51·8
125	53·3	48·2	53·3	53·3	53·5	53·2	49·6	51·0	47·6	51·5	50·8	50·5
150	49·9	45·0	53·2	53·2	53·4	53·2	47·6	48·0	46·8	47·9	48·5	49·4
175	46·8	44·0	53·2	53·3	53·2	48·1	46·7	46·2	45·2	46·2	47·5	47·8
200	45·8	43·8	52·6	48·5	46·0	45·8	45·4	45·4	44·9	44·2	45·6	47·4
225	44·7	43·5	48·5	44·0	...	44·0	44·8	44·4	44·7	43·2	...	45·8
250	44·0	43·4(240)	46·3(240)	...	43·8(235)	...	44·5	44·2	44·2	42·9	43·5	44·0
300	43·0	...	...	...	...	...	43·6	43·8	43·6	42·8	42·8	43·0
400	...	...	...	...	...	...	43·0	43·0	43·1	...	...	...
500	...	...	...	...	...	...	...	42·8	42·8	...	...	...
700	...	...	...	...	...	...	...	42·2	...	...	...	...

Date	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.	1904. Sept. 13.
Time	6 a.m.	12 noon.	2.35 p.m.	6 p.m.	6.40 a m.	12 noon.	6 p.m.	6.15 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.
Wind	NE. 2-3.	SW. 1-2.	SW. 1-2.	Calm.	NE. 2-4.	SW. 1.	SW. 1-2.	NE. 1.	S. 0-3.	Calm.	NE. 1.	SW. ½-1.
Air Temp.	53·8	55·4	57·2	53·4	..	..	..	52·5	54·8	54·0	..	..
Depth. Feet.												
0	53·7	54·0	54·1	54·1	54·8	54·8	54·9	54·6	54·5	54·8	54·8	55·1
10	53·6	54·0	54·1	54·1	...	...	...	...	...	...	...	...
25	53·6	53·9	53·9	54·0	54·5	...	...	54·5	54·3	54·9	...	...
50	53·6	53·9	53·8	53·9	54·3	54·2	54·0	54·0	54·0	53·8	54·1	55·0
75	53·6	53·8	53·8	53·8	...	...	...	...	...	...	52·5	53·3
100	53·7	53·8	53·6	53·8	54·0	54·0	54·0	52·8	52·0	52·8	51·9	52·8
125	53·3	50·4	49·8	53·8	48·1	52·9	48·0	52·0	49·2	49·9	50·1	51·5
150	49·2	46·4	45·9	47·0	46·2	46·3	46·1	48·2	47·1	47·6	48·8	50·6
175	45·1	44·3	44·8	45·0	45·0	45·2	45·0	46·1	46·2	47·0	46·9	47·7
200	44·0	44·0	44·0	44·3	44·1	44·5	44·2	45·5	45·5	45·0	45·7	46·3
225	43·1	43·8	43·4	43·8	...	43·8	43·9	44·8	44·6	44·5	43·8	45·8
250	...	...	...	...	43·2	43·3	43·3	44·2	44·2	44·0	43·3	44·0
300	...	...	...	...	43·0	...	43·1	43·6	43·6	43·3	42·9	42·9
350	...	...	...	...	...	43·0	...	...	...	...	...	...
400	...	...	...	...	...	...	...	43·0	43·2	43·0	...	...
500	...	...	...	...	...	...	...	42·8	42·7	42·8	...	...
680	...	...	...	...	....	...	...	...	42·4	...	...	...

Date	1904. Sept. 13.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 14.
Time	6 p.m.	6 a.m.	12 noon.	2.30 p.m.	6 p.m.	6 a.m.	12 noon.	6 p.m.	11 a.m.	6 a.m.	12 noon.	6 p.m.
Position	Dores.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Near West Shore at Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.
Wind	Calm.	W.	NE. 3.	NE. 3.	NE. 1-2.	NW. 1.	NE. 3.	NE. 2.	NE. 1.	Calm.	NE. 3.	NE. 3.
Air Temp.	..	38·0	55·0	58·0	54·5	..	..	..	..	39·5	55·2	54·8
Depth. Feet.												
0	55·3	53·8	54·3	54·0	54·5	54·0	54·3	54·2	54·8	54·6	54·9	54·4
10	...	54·0	54·2	54·0	54·5	...	...	...	...	...	...	...
25	...	54·2	54·0	54·0	54·3	...	...	...	...	54·6	54·6	54·4
50	54·3	54·2	54·2	54·0	54·0	...	...	...	...	54·5	54·2	54·0
75	53·3	54·0	53·8	54·1	54·0	...	...	54·1	53·8	...	...	...
100	53·2	53·5	54·0	53·8	54·0	53·8	54·0	53·7	53·6	52·8	52·1	53·0
125	53·0	47·5	48·0	53·5	54·0	47·2	53·0	48·0	...	49·5	48·6	49·7
150	51·0	45·8	45·5	46·3	54·0	45·3	46·5	46·3	47·6	47·8	47·3	47·2
175	48·6	44·8	45·0	45·3	46·8	44·2	45·1	45·8	...	46·4	46·0	45·8
200	47·5	44·3	44·5	44·8	45·0	44·0	44·3	44·9	44·1	45·2	45·0	45·0
225	46·0	44·0	43·8	...	44·5	43·8	...	44·7	...	44·5	44·5	44·2
250	45·0	...	...	...	...	43·2	43·8	44·0	...	44·0	43·8	43·8
300	43·5	...	...	...	...	43·2	43·3	43·3	43·3	42·8	43·2	43·0
400	...	...	...	...	...	...	...	...	42·9	...	43·0	...
500	...	...	...	...	...	...	...	...	...	...	42·6	...
600	...	..	...	...	...	...	...	...	42·7	...	...	..
695	...	...	...	...	...	...	...	...	...	...	42·2	...

Date	1904. Sept. 14.	1904. Sept. 14.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	19 Sept
Time	6 a.m.	6 p.m.	6 a.m.	12 noon.	3 p.m.	6 p m.	6.20 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.
Position	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inv farig
Wind	Calm.	NE. 2.	Variable.	NE. 0-1.	SW. 1-2.	NE. 1-2.	N.-NW. 1.	NE. 3.	NE. 1-SW. 1.	SE. 1.	NE. 0.	NE.
Air Temp.	..	..	45·5	52·0	..	57·8	..	..	..	46·8	59·5	
Depth. Feet.												
0	54·9	54·8	54·2	55·0	54·9	54·8	54·2	54·8	54·6	54·6	55·6	54
10	...	...	54·0	54·5	54·4	54·6	...	...	...	...	...	..
25	...	...	54·4	54·5	54·2	54·2	54·3	...	...	54·5	55·6	54
50	54·8	53·5	54·4	54·5	54·2	54·0	54·3	54·3	54·6	54·1	54·2	53
75	53·5	53·0	54·4	54·2	54·1	54·0	...	...	54·3	...	...	..
100	52·9	52·4	54·2	54·2	54·0	54·0	54·3	54·0	53·8	52·9	52·4	52
125	52·8	51·5	54·2	54·5	53·0	47·0	53·7	50·5	49·3	51·4	49·9	49
150	51·5	49·0	50·0	48·3	47·3	46·5	48·8	47·0	47·8	48·1	47·6	47
175	48·0	46·1	45·3	47·5	46·5	46·0	46·8	46·9	...	46·2	45·8	46
200	46·2	44·7	44·5	47·2	46·0	45·5	45·9	45·6	44·9	45·0	44·8	44
225	44·8	43·5	44·0	46·4	45·8	45·4	45·0	44·8	44·0	44·0	44·0	43
250	43·2	43·4	...	...	...	...	44·5	44 0	43·7	43·6	43·7	43
300	42·8	42·9	...	...	...	...	43·2	43·2	43·0	42·8	43·0	42
350	...	...	...	...	...	...	43·0	...	...	...	...	..
400	...	...	...	...	...	...	...	...	...	...	42·8	..
500	...	...	...	...	...	...	...	...	...	...	42·7	..
700	...	...	...	...	...	...	...	...	...	...	42·2	..

Date	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 15.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	19 Sept
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	2.30 p.m.	6 p.m.	6.15 a.m.	12 noon.	6 p.m.	6 a.m.	12 n
Position	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inv fari
Wind	Calm.	NE. 1.	Calm.	N. 0-½.	SW. 1-2.	..	SW. 1.	S. 1-2.	SSW. 1.	S. 2.	S. 2.	SW.
Air Temp.	..	..	..	52·0	60·5	59·0	62·2	..	..	..	57·5	6
Depth. Feet.												
0	54·9	55·0	55·1	54·0	54·1	54·3	54·1	54·3	54·6	54·7	54·4	54
10	..	...	...	54·0	...	...	...	...	...	...	...	.
25	...	...	...	54·0	...	..	...	...	...	...	54·2	54
50	53·8	53·8	54·0	54·0	54·0	54·0	53·9	54·3	54·2	54·1	53·7	53
75	53·2	53·0	53·7	54·0	52·8	...	49·0	53·2	53·3	53·7	...	.
100	52·7	52·7	53·3	48·0	48·1	53·9	47·0	49·8	49·0	51·7	53·3	52
125	52·0	52·0	52·9	47·5	47·4	52·7	46·8	47·8	46·4	48·8	51·0	50
150	49·3	48·3	52·1	46·0	46·0	45·6	45·0	46·5	45·8	47·3	48·0	48
175	45·7	45·8	48·2	45·3	45·0	45·0	44·3	45·3	44·9	46·2	46·1	46
200	44·4	44·3	45·3	45·0	44·5	44·1	44·0	44·2	44·0	45·3	44·8	44
225	43·8	43·8	44·2	44·0	44·0	43·8	44·0	43·8	43·5	44·5	...	44
250	43·1	43·2	43·5	...	...	...	...	43·3	43·2	44·0	43·2	43
300	42·8	42·9	42·9	...	...	...	..	43·0	43·0	43·1	42·8	43
400	...	...	...	...	...	...	...	...	...	...	...	42
500	...	...	...	...	...	...	...	...	...	...	...	42
700	...	...	...	...	...	...	...	...	...	...	...	42

Date	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 16.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.
Time	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	5.45 p.m.	6.15 a.m.	12 noon.
Position	Inver-farigaig.	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.
Wind	SW. 1-5.	NE. ½.	SW. 1-2.	SW. 2-3.	SW. 1-2.	SW. 1-3.	SW. 2-4.	SW. 2-3.	SW. 4-5.	SSW. ½-1.	SWW. ½-3.	SW. 4-5.
Air Temp.	59·2	..	..	..	60·5	63·8	63·5	..	..	..	60·0	63·2
Depth. Feet.												
0	54·4	55·0	55·3	55·2	54·0	53·9	52·9	54·1	54·1	53·7	54·4	54 5
25	54·3	...	...	...	...	...	...	...	54·0	53·7	...	...
50	54·2	54·7	55·0	55·0	53·2	51·3	51·0	54·0	53·4	53·2	54·3	54·0
75	...	53·9	54·6	...	52·3	50·0	50·0	53·0	52·7	52·3	54·0	53·6
100	52·7	53·8	54·6	54·1	49·0	49·8	49·5	51·1	50·4	50·7	54·0	53·4
125	49·8	53·3	53·9	...	47·8	49·0	49·1	50·0	49·1	50·2	48·9	51·6
150	47·5	52·4	53·7	53·2	47·8	48·8	47·3	48·4	47·4	47·9	46·7	49·0
175	46·8	46·0	52·2	47·0	47·0	47·0	46·8	47·1	46·0	46·0	45·1	47·0
200	45·2	45·2	51·0	46·0	44·5	44·8	45·4	45·8	45·0	45·0	44·2	45·8
225	44·3	44·5	45·5	44·8	44·0	44·0	44·9	44·5	44·1	44·3	43·8	44·5
250	43·8	44·0	44·5	44·0	...	...	44·8	44·5	43·8	44·8	43·4	44·0
300	43·1	43·0	43·5	43·8	...	...	...	43·3	43·0	43·2	43·0	43·2
350	...	...	...	...	...	...	...	...	...	43·0	...	...
400	...	...	...	...	...	...	...	...	...	...	...	43·0
500	...	...	...	...	...	...	...	...	...	...	...	42·8
685	...	...	...	...	...	...	...	...	...	...	...	42·5

Date	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 17.	1904. Sept. 18.	1904. Sept. 18.	1904. Sept. 18.	1904. Sept. 18.	1904. Sept. 18.	1904. Sept. 18.	1904. Sept. 19.	1904. Sept. 19.
Time	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.
Position	Inver-farigaig.	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Dores.	Dores.	Dores.	Yacht.	Yacht.
Wind	SSW. 2.	SW. 1-2.	SW. 1.	SW. 2-3.	WNW. 2.	SSW. 1-4.	SW. 0-2.	SW. ½.	SW. 2-3.	SW. 1-2.	Calm.	Calm.
Air Temp.	63·8	..	..	..	59·8	63·0	60·0	..	..	..	53·0	66·5
Depth. Feet.												
0	54·6	55·1	55·4	55·2	52·2	51·7	51·0	55·3	55·0	55·0	52·5	55·2
25	...	...	...	...	...	51·4	51·3	...	..	...	52·0	52·3
50	...	55·2	55·4	55·5	51·3	50·5	50·0	55·4	54·8	55·0	...	52·3
75	53·8	...	...	...	50·4	50·0	49·5	...	...	...	51·0	52·0
100	53·8	54·8	54·8	55·6	49·8	49·1	49·5	54·8	54·7	54·7	51·0	51·8
125	51·4	54·7	54·7	55·7	49·4	47·7	49·0	54·8	...	...	50·3	50·0
150	48·8	54·4	51·4	54·4	48·8	45·9	47·3	49·5	53·5	54·0	49·4	49·2
175	47·0	50·8	45·3	46·2	47·0	44·3	45·4	45·5	46·0	46·5	46·5	46·5
200	45·8	45·0	44·2	44·5	46·0	44·0	45·0	44·2	44·5	45·0	46·0	44·9
225	45·0	43·8	...	...	45·2	43·2	44·9	...	...	...	45·3	44·1
250	44·0	43·2	43·0	43·2	...	43·0	44·1	43·0	43·2	43·7	44·5(235)	...
300	43·4	42·8	42·9	43·0	...	...	...	42·9	43·0	42·9	...	...

Date	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.
Time	2.30 p.m.	6 p.m.	3.30 p.m.	4.40 p.m.	6.40 a.m.	12 noon.	6 p.m.	6.20 a.m.	12.30 p.m.	5.35 p.m.	12 noon.	6 p.m.
Position	Yacht.	Yacht.	Glendoe.	Horse-shoe.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	White-field.	White-field.
Wind	NE. ½.	S. 1.	NE. ½.	S. 0-1.	SSW. ½.	Calm.	NNE. ½.	SW-W. ½-1.	NEE. 0-½.	SW. ½-1.	Calm.	SW.
Air Temp.	62·5	61·2	..	..	..	..	..	55·0	59·8	61·8	..	..
Depth. Feet.												
0	53·8	55·8	55·3	55·0	54·0	54·2	53·9	54·1	54·9	54·8	57·0	55·0
10	...	...	53·0	...	...	53·4	...	...	...	...	...	...
25	52·4	52·8	...	...	53·2	53·1	...	...	...	...	55·4	54·7
50	52·4	52·5	52·5	...	53·1	...	53·2	54·1	...	...	54·6	54·5
75	52·4	52·3	...	...	53·0	53·1	...	54·0	54·0	54·0	54·0	54·0
100	52·0	52·0	51·8	52·0	52·7	52·8	52·8	53·8	54·0	53·8	53·8	53·8
125	51·6	52·0	...	...	50·0	51·2	51·0	49·7	52·5	51·3	53·2	50·7
150	50·4	50·1	49·8	...	49·6	49·0	48·9	46·8	47·4	46·9	46·2	47·0
175	49·3	49·3	....	...	46·0	47·2	46·0	46·0	45·4	...	45·7	45·7
200	46·0	46·8	47·0	46·1	45·1	45·9	45·2	45·0	44·8	44·8	44·9	45·0
225	44·8	44·9	...	...	44·5	45·0	44·5	44·2	44·0	44 2	44·3	44·7
250	...	44·0	44·0	...	44·0	43·9	43·9	44·0	43·5	43·9	44·0	44·3
300	...	...	...	...	43·2	43·2	43·0	43·2	43·2	43·2	43·3	43·7
400	...	...	...	...	...	...	...	...	42·7	...	...	...
500	...	...	...	...	...	...	...	...	42·6	...	...	...
700	...	....	...	...	...	...	...	...	42·3	...	...	...

Date	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 19.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6.20 a.m.	12.40 p.m.	5.40 p.m.
Position	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.
Wind	SW. 1.	Calm.	Calm.	Calm.	SW. airs.	SW. 1.	NNW. 1.	Calm.	Calm.	E. 1.	SW. 2.	SW. 1.
Air Temp.	..	..	..	45·0	63·5	58·0	..	..	..	47·8	63·6	60·0
Depth. Feet.												
0	55·0	55·8	56·2	53·8	54·5	53·4	53·5	56·9	54·7	54·1	54·5	54·3
5	...	...	...	...	...	...	...	53·9	...	...	...	...
25	...	...	...	54·0	54·5	...	...	...	53·6	...	...	...
50	55·0	54·8	54·8	53·0	53·2	52·8	53·3	53·2	53·3	...	...	...
75	...	...	...	52·5	53·0	...	...	...	...	54·0	54·0	54·0
100	54·7	54·8	54·0	52·5	53·0	52·4	53·3	52·7	53·1	53·6	53·8	52·8
125	53·2	54·3	47·4	52·3	52·5	50·0	52·4	52·3	52·5	49·0	51·1	49·8
150	47·0	48·0	46·0	49·8	49·8	47·2	51·1	48·8	47·6	47·6	48·2	48·0
175	45·4	46·0	44·8	47·0	47·4	45·5	46·4	45·5	45·0	45·8	46·0	45·6
200	44·5	45·0	44·2	45·3	45·5	44·2	45·0	44·7	44·9	45·2	44·6	45·1
225	43·8	...	...	44·2	44·3	43·8	44·1	44·0	43·3	44·2	44·0	44·3
250	42·9	43·8	43·6	...	43·5	43·8	43·7	43·2	43·0	43·5	43·6	43·9
300	...	43·0	43·0	...	...	...	43·0	43·0	42·9	43·1	43·2	42·8
350	...	...	...	...	...	...	...	42·9	...	...	...	...
400	...	...	...	...	...	...	...	...	...	...	43·0	...
500	...	...	...	...	...	...	...	...	...	...	42·8	...
690	...	...	...	...	...	...	...	...	...	...	42·2	...

Date	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 20.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.
Position	White-field.	White-field.	White-field.	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.
Wind	NW.	SW.	SW.	Calm.	SW. 1.	SW. 1-2.	Calm.	Calm.	Calm.	NNW. ½-1.	Calm.	Variable NNW.
Air Temp.	..	..	..	..	..	..	38·0	65·0	56·5	..	..	..
Depth. Feet.												
0	54·7	55·5	55·0	55·0	55·5	55·2	53·3	55·5	54·6	53·2	54·5	57·0
5	...	...	...	...	...	...	..	...	...	...	...	54·2
25	54·6	55·0	55·0	...	...	...	53·3	53·0	...	...	...	...
50	54·4	54·5	55·0	54·8	54·8	54·8	53·0	53·0	53·0	...	53·3	53·5
75	53·9	54·0	54·5	...	...	...	52·5	52·8	53·0	...	...	...
100	53·5	53·1	54·0	54·5	54·0	54·0	52·5	52·4	52·8	53·1	53·1	53·2
125	49·0	49·7	49·8	52·8	51·8	52·6	50·0	51·2	50·2	50·7	51·0	52·9
135	...	...	...	...	...	..	...	...	...	47·9	...	...
150	47·2	48·2	48·7	46·0	46·9	46·9	46·0	46·0	45·5	45·5	46·3	48·8
175	46·4	47·7	47·3	45·4	45·9	45·9	44·8	44·2	44·6	44·5	44·2	46·0
200	45·3	45·9	46·1	44·6	45·0	45·1	44·0	43·8	43·6	43·3	43 6	44·2
225	44·8	45·5	45·2	...	...	...	43·5	43·3	43·0	...	..	...
250	44·2	44·5	45·0	43·8	43·9	44·4	43·0	...	...	43·0	43·1	43·2
300	43·6	43·9	44·0	43·0	43·2	43·8	...	...	...	42·9	43·1	43·0

Date	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 21.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.
Time	6.30 a.m.	12 noon.	5.40 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.
Position	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	White-field.	White-field.	White-field.	Dores.	Dores.	Dores.	Yacht.	Yacht.	Yacht.
Wind	E.-SW. 1.	W. ½, S. 1.	SW. 1.	SWW.	Calm.	SW.	SW. 1.	SW. ½.	Calm.	Calm.	Calm.	NE. 2-3.
Air Temp.	44·5	54·2	55·2	..	..	..	..	..	..	39·0	59·0	54·8
Depth. Feet.												
0	54·2	55·0	55·0	54·9	56·4	55·9	55·0	55·7	56·2	53·2	54·2	53·6
25	...	...	...	54·9	54·9	54·9	...	...	...	53·2	53·5	...
50	...	...	...	54·9	54·7	54·8	55·0	55·0	54·9	53·2	53·5	53·6
75	54·1	54·0	54·1	54·6	54·2	54·0	...	...	54·5	53·2	53·5	...
100	53·5	52·5	51·5	54·0	52·8	53·1	54·3	54·3	51·5	53·0	53·2	53·0
125	51·0	51·0	49·8	51·2	50·9	50·0	49·1	51·6	48·5	53·0	53·2	53·0
150	48·9	48·0	46·8	49·7	49·0	48·6	47·6	48·9	48·0	49·3	49·5	49·8
175	47·1	46·1	45·5	48·4	48·0	47·1	46·2	47·8	47·8	45·8	46·0	45·3
200	45·1	45·0	44·8	47·0	46·1	45·2	46·0	46·5	47·5	45·0	44·8	44·0
225	44·3	44·0	44·2	45·5	45·0	44·9	...	...	45·8	44·5	43·5	43·3
250	43·6	43·7	43·8	44·9	44·0	44·4	45·2	45·4	45·1	44·0	43·0	...
300	43·0	43·0	43·0	43·9	43·5	43·5	44·7	44·5	43·5	..	...	...
400	...	42·7	...	...	...	...	...	...	...	...	...	...
500	...	42·6	...	...	...	..	...	...	...	...	...	...
700	...	42·2	...	...	...	...	...	...	...	...	...	...

Date	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.	1904. Sept. 22.
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6.15 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.
Position	Inver-morriston.	Inver-morriston.	Inver-morriston.	White-field.	White-field.	White-field.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	Dores.	Dores.	Dores.
Wind	Variable airs.	Southerly airs.	NE. 2.	NW.	NE.	NE.	SW. 1.	NE. 1.	NE. 3.	SW ½.	NE. ½.	Calm.
Air Temp.	..	..	..	..	..	..	45·2	55·2	55·0	..	..	..
Depth. Feet.												
0	53·7	54·6	54·0	55·0	56·9	55·0	54·2	55·8	54·8	54·9	57·0	55·4
5	...	54·0	...	...	...	...	...	...	...	...	...	...
25	...	...	...	55·0	54·9	...	...	..	...	...	...	...
50	53·5	53·6	53·5	54·8	54·8	54·8	...	...	...	55·0	55·0	54·8
75	...	53·6	...	54·2	54·0	...	54·0	54·0	53·8	54·5	54·8	54·2
100	53·3	53·2	53·2	52·2	52·5	53·5	52·2	53·5	52·3	53·0	52·8	51·2
125	52·9	52·8	51·3	50·6	50·4	51·9	48·6	50·1	50·2	49·6	49·8	49·7
150	51·1	49·7	47·3	48·8	48·3	49·0	46·6	46·8	47·2	48·0	48·1	48·1
175	46·2	45·1	45·0	47·0	47·0	47·1	45·4	45·8	45·9	47·0	47·0	47·6
200	44·5	44·3	44·3	45·8	45·4	46·0	44·7	45·1	44·3	46·0	45·9	45·4
225	43·9	...	43·9	44·5	44·5	45·0	44·0	44·9	44·5	44·4	44·0	...
250	43·1	43·0	43·1	44·0	44·0	44·2	43·5	44·4	44·0	43·2	43·4	43·5
300	42·9	42·9	43·0	43·5	43·5	43·5	42·9	43·5	42·8	42·8	42·9	43·0
400	...	...	...	...	...	...	...	43·0	...	...	...	...
500	...	...	...	...	...	...	...	42·7	...	...	...	...
700	...	...	...	...	...	...	...	42·4	...	...	...	...

Date	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 p.m.	6.15 a.m.	12 noon.	5.40 p.m.	6 a.m.	12 noon.	6 p.m.
Position	Yacht.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	Inver-farigaig.	White-field.	White-field.	White-field.
Wind	NE. 1.	NE. ½.	NE. 2.	NE. 1–2.	ENE. 1.	ENE. 1.	NE. 2.	NE. 1–2.	NE. 2.	NE.	NE.	NE.
Air Temp.	49·5	58·5	54·0	..	..	..	49·5	54·0	54·0	..	..	..
Depth. Feet.												
0	53·8	54·0	54·0	53·9	54·0	53·8	54·3	55·0	54·4	54·8	55·7	55·0
25	53·8	...	...	...	...	...	...	...	...	...	...	...
50	53·5	53·8	53·8	53·9	53·7	53·9	..	...	...	54·5	54·5	54·5
75	53·5	53·8	54·0	...	...	...	53·9	54·1	54·0	...	...	54·4
100	52·0	53·5	53·5	53·9	53·4	53·7	52·6	53·5	52·0	53·1	53·0	53·0
125	52·3	53·4	52·8	51·0	52·1	51·3	48·2	49·3	51·2	51·9	51·7	51·0
150	49·0	48·8	48·5	46·9	47·1	47·2	46·5	46·5	46·1	49·0	49·0	47·9
175	44·8	45·2	46·0	45·2	45·1	45·8	46·1	45·8	45·7	46·5	47·3	46·5
200	43·6	43·8	45·0	44·9	45·0	44·8	45·0	44·9	44·6	45·0	45·8	45·2
225	43 3	43·4	44·0	...	...	...	44·4	44·0	44·2	...	44·5	...
250	...	...	...	44·0	44·1	44·0	43·2	43·5	43·6	44·0	43·9	44·1
300	...	...	...	43·1	43·5	43·5	42·8	43·2	43·0	43·8	43·5	43·8
400	...	..	...	...	...	...	...	42·8	...	...	...	...
500	...	...	...	...	...	...	...	42·8	..	...	...	...
685	...	...	...	...	...	...	...	42·3	...	...	...	...

Date	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 23.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.	1904. Sept. 24.
Time	6 a.m.	12 noon.	6 p.m.	6 a.m.	12 noon.	6 a.m.	11 a.m.	6 a.m.	11 a.m.	6 a.m.	11 a.m.	6 a.m.
Position	Dores.	Dores.	Dores.	Yacht.	Yacht.	Inver-morriston.	Inver-morriston.	Inver-farigaig.	Inver-farigaig.	White-field.	White-field.	Dores.
Wind	Calm.	Calm.	NE. 1.	NE. 0–1.	NE. 1–2.	NNW. ½.	NE. 2.	NE. 1.	NE. 2.	NE.	NE.	Calm.
Air Temp.	..	..	..	50·8	52·2	..	..	49·5	51·1	..	..	..
Depth. Feet.												
0	54·9	56·2	55·0	53·9	53·9	54·1	54·0	54·2	54·3	54·8	54·6	54·5
50	54·8	54·8	54·6	53·9	53·8	...	54·0	...	...	54·5	54·5	54·2
75	54·0	54·0	54·0	...	...	...	...	53·4	54·0	54·0	54·2	52·8
100	52·1	51·3	51·8	53·9	53·8	53·8	...	52·5	52·4	52·5	52·8	51·7
125	50·7	50·0	50·5	53·5	53·8	51·9	53·7	52·0	49·3	51·5	51·4	50·2
150	49·5	49·0	49·8	48·1	52·0	47·3	48·3	46·4	47·2	48·2	48·0	48·8
175	48·0	47·3	47·0	45·4	45·1	45·1	...	45·8	45·4	46·7	46·1	46·0
200	45·5	45·0	45·0	45·0	45·0	45·0	45·0	44·9	44·6	45·0	45·0	44·8
225	44·0	...	...	44·9	44·9	...	...	44·0	44·0	...	44·2	...
250	43·4	43·7	43·6	...	...	44·0	43·8	43·7	43·7	44·1	43·8	43·7
300	43·0	42·9	43·0	...	...	43·2	43·0	43·0	43·3	43·4	43·3	43·0
400	...	..	...	...	...	...	...	...	43·0	...	...	...
500	...	...	...	...	...	...	...	...	42·8	...	...	...
670	...	...	...	...	...	...	....	...	42·3	...	...	...

Date	1904. Sept. 24.	1904. Sept. 25.	1904. Sept. 26.	1904. Sept. 27.	1904. Sept. 28.	1904. Sept. 29.	1904. Sept. 30.	1904. Oct. 1.	1904. Oct. 2.	1904. Oct. 3.	1904. Oct. 4.	1904. Oct. 5.
Time	11 a.m.	2.30 p.m.	1.50 p.m.	2.30 p.m.	2.30 p.m.	2.45 p.m.	2.30 p.m.	2.30 p.m.	2.15 p.m.	2 p.m.	2.30 p.m.	2.15 p.m.
Position	Dores.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. ½.	NE. 2–3.	SW. 1.	SW. 1–2.	SW. 1–2.	SSW. 2–3.	SW. 2.	SW. 2–3.	SW. 1.	WSW. 2 gusts.	SW. 3–4.	SW. 1.
Air Temp.	..	..	53·9	58·0	58·0	63·0	56·3	50·5	53 2	56·6	51·2	53·0
Depth. Feet.												
0	54·5	53·8	53·8	53·9	53·8	53·1	57·8	51·0	51·0	51·0	44·7	51·0
25	...	53·6	53·8	53·8	53·3	53·0	51·1	51·1	51·0	50·6	44·2	50·7
50	54·1	53·6	53·7	53·2	52·9	52·5	51·0	51·9	50·3	50·0	43·8	50·4
75	53·0	53·4	53·7	48·8	52·4	51·5	49·2	50·9	50·0	49·6	43·3	50·1
100	52·0	53·5	53·6	47·8	51·1	49·4	48·4	51·0	48·8	49·4	43·3	49·0
125	50·9	53·7	46·8	46·7	50·3	47·4	47·0	49·5	47·2	49·0	43·1	48·3
150	49·0	46·0	45·5	46·1	49·3	45·2	45·1	48·9	45·3	48·2	43·0	48·2
175	47·4	45·0	44·8	44·8	48·2	44·3	44·2	47·4	45·0	47·3	43·0	47·9
200	45·0	44·6	44·2	43·9	46·0	43·7	43·6	46·7	44·0	46·4	43·0	47·5
225	...	44·1	43·6	43·3	44·6	43·0	43·0	46·0	43·4	44·7	42·8	47·0
250	43·6	...	...	...	...	...	...	...	...	...	...	...
300	43·0	...	...	...	...	...	...	...	...	...	...	...

Date	1904. Oct. 6.	1904. Oct. 7.	1904. Oct. 8.	1904. Oct. 9.	1904. Oct. 10.	1904. Oct. 11.	1904. Oct. 12.	1904. Oct. 13.	1904. Oct. 14.	1904. Oct. 15.	1904. Oct. 16.	1904. Oct. 17.
Time	2.20 p.m.	2.20 p.m.	2.30 p.m.	2 p.m.	2 p.m.	2.30 p.m.	2.15 p.m.	1.50 p.m.	2.15 p.m.	2.15 p.m.	2.15 p.m.	2.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	E. 1.	SW. 2.	WNW. 2.	SW. 3.	SW. 3.	SSW. 4.	WNW. 1.	S. 4.	SW. 2.	SW. 2.	SW. 2.	WSW. 2-3
Air Temp.	48·8	50·5	44·1	53·0	51·6	53·3	52·4	53·9	54·1	53·0	50·0	47·3
Depth. Feet.												
0	51·1	51·5	51·2	51·7	49·7	49·2	49·3	49·7	49·5	49·4	49·4	47·9
25	51·1	51·5	51·2	50·8	49·5	49·1	49·0	49·7	49·5	49·2	49·3	46·9
50	51·1	51·4	51·1	50·8	48·3	49·0	49·0	49·5	49·3	49·5	49·3	45·6
75	...	51·3	51·0	50·5	47·0	49·0	49·0	...	49·3	49·5	49·2	45·0
100	50·8	50·5	50·0	50·3	46·2	49·1	48·0	49·5	49·2	49·5	49·2	44·2
125	...	48·0	49·2	49·8	45·1	48·2	46·8	49·5	49·0	49·3	48·9	43·8
150	50·3	46·6	48·1	47·5	44·6	47·8	46·1	49·5	47·0	49·1	46·0	43·2
175	...	44·3	46·3	45·8	44·0	47·8	45·1	49·5	45·0	48·0	44·5	43·1
200	49·5	43·8	45·0	44·5	43·8	47·0	44·8	49·3	43·5	45·8	43·8	43·0
225	49·1	43·2	43·0	43·5	43·3	45·9	44·0	49·5	43·2	44·8	43·1	42·9

Date	1904. Oct. 18.	1904. Oct. 19.	1904. Oct. 20.	1904. Oct. 21.	1904. Oct. 22.	1904. Oct. 23.	1904. Oct. 24.	1904. Oct. 25.	1904. Oct. 26.	1904. Oct. 27.	1904. Oct. 28.	1904. Oct. 29.
Time	2.30 p.m.	2.30 p.m.	2.30 p.m.	2.30 p.m.	2.15 p.m.	2.25 p.m.	2.30 p.m.	2.45 p.m.	2.30 p.m.	2.20 p.m.	2.30 p.m.	2.40 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1-2.	SW. 1-2.	Calm.	SW. 1-2.	SSW. 3.	Calm.	SW. 2.	SW. 2.	SW. 1.	SW. 1-2.	Calm.	SW. 3.
Air Temp.	55·1	57·2	55·1	58·4	53·2	49·5	50·0	50·0	54·0	53·0	54·0	52·0
Depth. Feet.												
0	47·1	49·0	50·0	49·6	48·7	48·4	48·8	48·3	46·3	48·2	48·3	48·3
25	47·1	48·9	49·0	49·4	48·7	48·4	48·7	48·3	46·2	48·0	48·2	48·3
50	47·0	48·8	49·0	49·2	48·4	48·2	48·6	48·3	46·2	48·0	48·2	48·3
75	47·0	48·7	49 2	49·1	48·1	48·0	48·6	47·8	46·0	48·0	48·2	48·4
100	46·8	48·7	48·7	49·1	48·0	47·9	48·6	46·8	45·0	47·9	48·1	48·4
125	...	...	48·6	49·0	47·8	47·7	48·5	46·0	44·9	47·9	48·1	48·4
150	46·7	48·3	48·4	49·0	46·8	47·8	48·4	45·0	44·5	47·9	48·0	48·5
175	46·7	48·3	47·8	48·9	45·0	46·9	48·4	44·1	43·8	47·8	46·0	48·5
200	46·6	47·2	45·2	48·5	44·2	45·1	48·2	43·9	43·2	47·5	45·4	48·0
225	46·4	46·0	44·5	47·5	43·9	43·8	48·2	43·2	43·0	46·2	44·9	47·8

Date	1904. Oct. 30.	1904. Oct. 31.	1904. Nov. 1.	1904. Nov. 2.	1904. Nov. 3.	1904. Nov. 4.	1904. Nov. 5.	1904. Nov. 6.	1904. Nov. 7.	1904. Nov. 8.	1904. Nov. 9.	1904. Nov. 10.
Time	2 p.m.	2 p.m.	2 p.m.	2.10 p.m.	2 p.m.	2.40 p.m.	2 p.m.	2.20 p.m.	2.20 p.m.	2 p.m.	2.45 p.m.	2.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. 1.	NE. 1-2.	NE. 2.	SW. 4.	S. 3-4.	SW. 3.	SW. 3-4.	SW. 1-2.	SW. 2.	SW. 1-2.	NE. 3.	Calm.
Air Temp.	..	50·0	49·0	49·5	53·5	53·9	49·0	44·9	40·3	45·2	..	36·2
Depth. Feet.												
0	49·2	49·1	49·2	49·2	45·3	47·4	48·0	47·3	47·2	47·3	47·8	47·3
25	49·0	48·9	49·2	49·2	45·1	47·3	48·0	47·3	47·4	47·4	...	...
50	49·0	48·9	49·2	49·2	45·0	47·4	48·0	47·3	47·7	47·4	47·3	47·2
75	48·9	49·0	49·2	49·2	44·0	47·3	48·0	47·2	47·8	47·3	...	...
100	49·0	49·0	49·2	49·2	43·9	47·3	48·0	47·0	47·8	47·3	47·3	47·2
125	49·0	49·0	49·2	49·2	43·8	47·1	47·5	46·3	47·5	47·3	...	...
150	49·0	47·2	49·2	49·0	43·2	47·1	47·5	45·8	47·5	47·3	47·0	47·2
175	49·0	44·0	49·2	45·0	43·1	47·0	47·5	45·0	47·4	47·2	...	...
200	49·0	44·0	49·2	44·0	43·0	47·0	46·3	44·0	47·4	47·1	47·0	...
225	48·8	43·8	49·2	43·5	43·0	47·0	...	43·9	47·4	45·9	42·0	47·1

Date	1904. Nov. 11.	1904. Nov. 12.	1904. Nov. 13.	1904. Nov. 14.	1904. Nov. 15.	1904. Nov. 16.	1904. Nov. 17.	1904. Nov. 18.	1904. Nov. 19.	1904. Nov. 20.	1904. Nov. 21.	1904. Nov. 22.
Time	2.30 p.m.	2.30 p.m.	2.15 p.m.	2.15 p.m.	2.15 p.m.	2 p.m.	2.15 p.m.	2 p.m.	2.15 p.m.	2.30 p.m.	2 p.m.	2.30 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SW. 2.	SW. 4.	SW. 2.	SSW. 5.	SSW. 2-3.	SW. 4.	SSW. 3.	SW. 4.	SW. 1.	SSW. 0-1.	NE. 2.
Air Temp.	43·4	49·8	53·5	54·5	50·0	50 0	52·1	51·0	38·5	35·0	29·0	..
Depth. Feet.												
0	47·4	47·2	47·3	47·0	46·6	47·0	46·6	46·2	45·8	45·4	46·3	46·4
25	47·1	47·2	47·5	47·0	46·4	47·0	46·5	46·2	45·8	45·5	46·2	...
50	47·0	47·0	47·5	46·9	46·4	47·0	46·5	46·0	45·8	45·5	46·3	46·4
75	47·0	47·0	47·3	46·5	46·2	...	46·5	45·3	45·8	45·5	46·3	...
100	47·0	47·0	47·0	46·1	46·0	...	46·4	45·3	45·7	45·5	46·1	46·2
125	47·1	47·1	47·0	45·7	45·5	46·5	46·3	44·2	45·4	...	46·1	...
150	47·0	47·0	46·8	45·7	45·4	46·5	46·2	44·0	45·2	...	46·1	...
175	47·0	47·0	46·5	45·7	45·2	46·5	46·0	44·0	45·2	...	46·1	...
200	46·9	45·3	46·2	44·5	45·0	46·5	45·5	43·4	45·2	...	...	...
225	43·9	43 9	45·7	44·2	44·7	46·5	...	43·4	45·0	...	46·1	46·2

Date	1904. Nov. 24.	1904. Nov. 25.	1904. Nov. 26.	1904. Nov. 27.	1904. Nov. 28.	1904. Nov. 29.	1904. Nov. 30.	1904. Dec. 1.	1904. Dec. 2.	1904. Dec. 3.	1904. Dec. 4.	1904. Dec. 5.
Time	2.30 p.m.	2.30 p.m.	2.30 p.m.	2.15 p.m.	2.15 p.m.	2.30 p.m.	2.15 p.m.	2.15 p.m.	2.15 p.m.	2.30 p.m.	2.15 p.m.	2.20 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	Calm.	Calm.	Calm.	Calm.	SW. 1.	SW. 3-4.	SW. 2-3.	SW. 2.	WSW. 0-1.	NE. 1.	SW. 3.
Air Temp.	38·1	..	38·1	40·5	41·3	45·0	49·8	45·8	41 0	41·9	45·8	41·0
Depth. Feet.												
0	46·1	46·2	46·1	46·0	46·0	46·0	46·0	45·0	44·7	44·7	44·7	43 3
25	46·3	46·2	46·1	46·0	46·0	46·0	46·0	44·9	44·7	44·4	...	43 4
50	46·2	46·2	46·1	46·0	46·0	46·0	45·8	45·0	44·3	44·4	...	43·4
75	46·1	46·2	46·1	46·0	46·0	46·0	45·8	44·9	44·3	44·2	...	43·4
100	46·2	46·2	46·0	46·0	45·9	46·0	45·2	44·2	44·3	44·2	...	43·3
125	46·2	46·2	46·0	46·0	46·0	46·0	45·2	44·2	44·2	44·2	...	43·3
150	46·2	46·2	46·0	46·0	45·8	45·8	45·0	44·2	44·2	44·0	...	43·1
175	46·2	46·2	45·6	45·8	45·8	45·8	45·0	44·2	...	44·0	...	43·2
200	46·2	46·1	45·5	45·8	45·8	45·7	44·5	...	44·3	44·0	...	43·0
225	46·2	46·1	45·2	45·4	45·5	45·7	44·0	44·0	44·2	44·0	44·3	43·0

Date	1904. Dec. 6.	1904. Dec. 7.	1904. Dec. 8.	1904. Dec. 9.	1904. Dec. 10.	1904. Dec. 11.	1904. Dec. 13.	1904. Dec. 14.	1904 Dec. 15.	1904. Dec. 16.	1904. Dec. 17.	1904. Dec. 18.
Time	2 p.m.	2 p.m.	2.30 p.m.	2 p.m.	2.30 p.m.	2 p.m.	3.15 p.m.	2.20 p.m.	2.20 p.m.	2.15 p.m.	2.30 p.m.	2.30 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	NE. ½.	Calm.	NE. 3.	NE. 2.	SW. 2.	Calm.	SW. 2.	SW. 0-1.	SW. 4.	SW. 3.	..
Air Temp.	36·2	35·0	33·6	35·9	36·4	38·5	33·2	40·2	42·1	52·4	48·0	42·4
Depth. Feet.												
0	43·0	44·3	44·8	45·0	44·6	44·7	44·2	44·3	44·2	43·8	43·2	43·1
25	43·1	44·3	...	45·0	44·5	44·7	...	44·2	44·2	...	...	...
50	43·2	44·3	45·0	44·9	44·4	44·8	44·4	44·2	44·2	43·2	42·9	43·0
75	43·2	44·4	...	44·8	44·5	44·7	...	44·2	44·2	...	...	...
100	43·2	44·2	44·9	45·0	44·5	...	44·3	44·2	...	43·3	43·0	43·0
125	43·2	44·3	...	44·6	...	44 5	...	...	44·0	...	...	...
150	43·1	44·1	44·9	44·6	...	44·8	...	44·2	44·0	43·3	43·0	43·0
175	43·2	44·3	...	44·4	...	44·8	...	44·2	44·0	...	...	...
200	43·2	44·3	44·9	44·3	...	44·8	44·2	44·2	44·0	43·3	43·0	...
225	43·1	44·0	44·8	...	...	44·8	...	44·1	44·0	...	...	43·0

Date	1904. Dec. 19.	1904. Dec. 20.	1904. Dec. 21.	1904. Dec. 22.	1904. Dec. 23.	1904. Dec. 24.	1904. Dec. 25.	1904. Dec. 26.	1904. Dec. 27.	1904. Dec. 28.	1904. Dec. 29.	1904. Dec. 30.
Time	2 p.m.	3.15 p.m.	2.30 p.m.	2 p.m.	2 p.m.	10.45 a.m.	3.15 p.m.	2.15 p.m.	2.20 p.m.	2.30 p.m.	2 p.m.	2.15 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 0-1.	Calm.	SSW. 3.	SW. 1.	Calm.	Calm.	NE. 3.	Calm.	SSW. 1-2.	SW. 1.	SSW. 3.	N. 1.
Air Temp.	41·3	45·0	47·0	45·0	46·0	42·8	43·0	38·0	42·9	46·5	53·0	42·3
Depth. Feet.												
0	43·2	43·5	43·9	43·2	43·5	43·4	43·3	43·4	43·4	43·6	43·3	43·0
25	43·2	43·5	...	...	...	...	...	...	...	...	...	...
50	43·2	43·5	...	43·2	43·3	43·5	43·4	43·5	43·4	43·6	43·2	43·0
100	43·2	43·4	...	43·1	43·2	43·3	43·3	43·6	43·4	43·6	43·2	43·0
150	43·1	43·1	43·8	43·1	43·2	43·0	43·3	43·4	43·4	43·6	43·2	43·0
200	43·2	43·2	43·5	43·1	43·2	43·2	43·3	43·6	43·4	43·8	43·2	43·0
225	43·2	..	...	...	...	...	...	...	...	...	...	...

Date	1904. Dec. 31.	1905. Jan. 1.	1905. Jan. 2.	1905. Jan. 3.	1905. Jan. 4.	1905. Jan. 5.	1905. Jan. 6.	1905. Jan. 7.	1905. Jan. 9.	1905. Jan. 10.	1905. Jan. 12.	1905. Jan. 13.
Time	2.30 p.m.	2.15 p.m.	2.20 p.m.	2.20 p.m.	1.45 p.m.	2.10 p.m.	2.15 p.m.	2.40 p.m.	2 p.m.	2.45 p.m.	Noon.	2.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SW. 1-2.	SW. 3-4.	SW. 3.	SW. 2-3.	SW. 2.	W. 3.	SW. 2.	W. 1.	SW. 2.	SW. 1-2.	SW. 0-1.
Air Temp.	39·5	42·9	47·1	49·1	46·2	41·0	48·5	49·5	..	..	..	..
Depth. Feet.												
0	43·0	43·1	43·0	43·0	43·0	...	43·0	43·0	42·8	42·9	42·8	42·8
50	43·0	43·1	43·0	43·0	43·0	43·0	43·0	43·0	42·8	42·9	42·8	42·8
100	43·0	43·0	43·0	43·0	43·0	43·0	43·0	43·0	42·8	42·9	42·6	42·7
150	43·0	43·0	43·0	43·0	43·0	43·0	43·0	43·0	42·9	42·9	42·6	42·6
200	43·0	43·0	43·0	43·0	43·0	43·0	43·0	43·0	42·9	42·9	42·6	42·6

Date	1905. Jan. 18.	1905. Jan. 19.	1905. Jan. 20.	1905. Jan. 21.	1905. Jan. 22.	1905. Jan. 23.	1905. Jan. 24.	1905. Jan. 25.	1905. Jan. 26.	1905. Jan. 27.	1905. Jan. 30.	1905. Jan. 31.
Time	2.20 p.m.	2 p.m.	2 p.m.	2.45 p.m.	2.50 p.m.	1.45 p.m.	2.40 p.m.	2.30 p.m.	2.15 p.m.	2.45 p.m.	2.30 p.m.	2.20 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	W. 0-1.	SW. 0-1.	NE. 2-3.	SE. 2.	W. 2.	SW. 4.	WSW. 1-2.	N. 1-2.	SW. 1-2.	SW. 3.	SW. 4-5.	SW. 2.
Air Temp.	39·0	44·4	42·3	43·3	40·0	44·5	41·2	39·3	38·2	47·5	48·0	40·0
Depth. Feet.												
0	42·4	42·5	42·5	42·3	42·3	42·3	42·5	42·5	42·2	42·5	42·4	42·0
50	42·4	42·5	42·5	42·3	42·3	...	...	...	...	...	...	...
100	42·4	42·6	42·5	42·3	42·3	42·3	42·5	42·5	42·2	42·5	42·2	41·9
150	42·3	42·6	42·5	42·3	42·3	...	...	...	...	...	...	...
200	42·3	42·5	42·4	42·3	42·3	42·3	42·3	42·3	42·2	42·3	42·2	41·8

Date	1905. Feb. 1.	1905. Feb. 2.	1905. Feb. 3.	1905. Feb. 4.	1905. Feb. 5.	1905. Feb. 6.	1905. Feb. 7.	1905. Feb. 8.	1905. Feb. 10.	1905. Feb. 11.	1905. Feb. 12.	1905. Feb. 13.
Time	2.30 p.m.	3 p.m.	2.30 p.m.	2.20 p.m.	1.45 p.m.	1.45 p.m.	2.25 p.m.	1.50 p.m.	3 p.m.	2 p.m.	2.40 p.m.	11.20 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1-5.	SW. 2.	SW. 2.	SW. 2-3.	SW. 3-4.	SW. 1-2.	SW. 1-2.	SSW. 3-4.	SW. 2.	NE. 1.	SW. ½.	SW. 2.
Air Temp.	41·0	36·3	38·2	46·0	49·1	44·2	44·0	48·0	39·1	34·5	33·8	47·2
Depth. Feet.												
0	42·0	42·0	42·1	41·3	41·8	41·8	41·7	41·9	41·8	42·0	42·0	42·0
100	42·0	42·0	42·0	41·2	41·9	41·8	41·7	41·8	41·9	41·8	42·0	41·9
200	42·0	41·8	42·0	41·2	41·9	41·3	41·5	41·6	41·7	41·8	41·8	41·9

Date	1905. Feb. 14.	1905. Feb. 15.	1905. Feb. 17.	1905. Feb. 19.	1905. Feb. 20.	1905. Feb. 21.	1905. Feb. 22.	1905 Feb. 23.	1905. Feb. 24.	1905. Feb. 25.	1905. Feb. 26.	1905. Feb. 27.
Time	2.30 p.m.	2.30 p.m.	2.45 p.m.	3.15 p.m.	1.45 p.m.	2.45 p.m.	2 p.m.	1.45 p.m.	2.45 p.m.	2 p.m.	5.30 p.m.	11.45 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1-2.	SW. 1-2.	NW. 2.	W. 2.	NE. 2.	Calm.	SW. 2.	Calm.	NE. 1-2.	S. 2.	SW. 4.	Calm.
Air Temp.	47·2	47·0	39·3	36·2	39·5	41·2	40·5	41·8	38·8	43·5	37·2	41·3
Depth. Feet.												
0	42·1	41·7	41·6	41·7	41·5	41·8	42·0	42·0	41·8	42·0	...	41·4
100	42·0	41·6	41·5	41·5	41·5	41·6	41·6	41·8	41·8	41·8	...	...
200	41·9	41·5	41·5	41·5	41·5	41·6	41·6	41·5	41·7	41·8	41·8	41·7

Date	1905. Feb. 28.	1905. Mar. 2.	1905. Mar. 2.	1905. Mar. 3.	1905. Mar. 4.	1905. Mar. 5.	1905. Mar. 6.	1905. Mar. 7.	1905. Mar. 8.	1905. Mar. 9.	1905. Mar. 10.	1905. Mar. 12.
Time	2.20 p.m.	11.10 a.m.	2·45 p.m.	2.15 p.m.	2·30 p.m.	2.30 p.m.	1.30 p.m.	4.35 p.m.	1.30 p.m.	3 p.m.	2.45 p.m.	9.15 a.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	NE. ½.	Calm.	Calm.	SW. 2-3.	SW. 1.	W. ½.	S. 3-4.	W. 3.	SW. 1-2.	W. 2.	SW. 1-2.	Calm.
Air Temp.	42·1	39·0	43·9	43·3	47·3	49·0	44·0	39·2	43·5	41·3	41·5	36·2
Depth. Feet.												
0	41·8	42·0	42·0	41·8	41·9	41·8	41·7	41·4	41·6	41·4	41·6	41·3
25	...	41·7	41·8	...	...	...	...	...	...	...	...	...
100	41·5	41·7	...	41·9	41·7	41·3	41·3	41·2	41·5	41·3	41·3	41·2
200	41·4	41·5	...	41·7	41·6	41·3	41·3	41·0	41·0	41·0	41·1	41·0

Date	1905. Mar. 13.	1905. Mar. 14.	1905. Mar. 16.	1905. Mar. 17.	1905. Mar. 18.	1905. Mar. 19.	1905. Mar. 20.	1905. Mar. 21.	1905. Mar. 22.	1905. Mar. 23.	1905. Mar. 24.	1905. Mar. 26.
Time	2.15 p.m.	10.15 a.m.	5.15 p.m.	2 p.m.	2.30 p.m.	3.30 p.m.	2.15 p.m.	3.15 p.m.	2.45 p.m.	2.20 p.m.	2.45 p.m.	1.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1-2.	SW. 1-2.	SW. 1.	SW. 1.	SW. 1-2.	SW. 1.	SW. 2-3.	SW. 3.	SSE. 3-4.	SW. 1-2.	NE. 2-3.	SW. 2.
Air Temp.	46·2	45·3	42·1	50·1	48·0	51·2	49·0	50·5	57·3	52·7	41·5	49·0
Depth. Feet.												
0	41·2	41·3	41·1	41·2	41·5	41·5	41·5	41·6	41·5	41·3	41·5	41·8
15	...	...	...	...	...	...	...	...	41·5	...	...	...
100	41·2	41·2	41·1	41·2	41·3	41·2	41·3	41·4	41·3	41·2	41·4	41·6
200	41·2	41·2	41·0	41·2	41·2	41·2	41·1	41·3	41·2	41·2	41·1	41·6

Date	1905. Mar. 27.	1905. Mar. 28.	1905. Mar. 29.	1905. Mar. 30.	1905. Mar. 31.	1905. Apr. 1.	1905. Apr. 2.	1905. Apr. 3.	1905. Apr. 4.	1905. Apr. 5.	1905. Apr. 6.	1905. Apr. 7.
Time	10.20 a.m.	2.30 p.m.	2.30 p.m.	2.20 p.m.	2.20 p.m.	2.30 p.m.	2.45 p.m.	2 p.m.	2.30 p.m.	2.45 p.m.	2.35 p.m.	2.45 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	Calm.	SW. 3-4.	SW. 3.	SW. 3.	SW. 2-3.	SW. 1.	W. 0-1.	SW. 1-2.	SW. 3.	N. 1.	W. 1.	NW. 2.
Air Temp.	44·8	44·1	50·2	50·0	45·6	44·5	48·3	56·0	51·0	42·5	36·0	39·5
Depth. Feet.												
0	41·8	41·6	41·3	41·3	41·2	41·2	41·5	41·8	41·9	41·6	41·9	41·9
30	41·4	...	...	...	...	...	...	...	...	...	...	...
100	41·4	...	41·2	41·2	41·2	41·2	41·2	41·4	41·6	41·6	41·5	41·9
200	41·3	41·4	41·3	41·2	41·2	41·2	41·2	41·2	41·6	41·5	41·5	41·7

Date	1905. Apr. 8.	1905. Apr. 9.	1905. Apr. 10.	1905. Apr. 11.	1905. Apr. 12.	1905. Apr. 13.	1905. Apr. 14.	1905. Apr. 15.	1905. Apr. 16.	1905. Apr. 17.	1905. Apr. 20.	1905. Apr. 21.
Time	1.45 p.m.	2.15 p.m.	4.30 p.m.	2.15 p.m.	2.15 p.m.	2.15 p.m.	2.30 p.m.	2.20 p.m.	3.15 p.m.	4.20 p.m.	2.45 p.m.	2.20 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	W. 2.	NW. 0-1.	SSW. 2-3.	SW. 1.	S. 2-3.	SSE. 2-3.	SE. 2-3.	SE. 2.	Variable.	NE. 1-2.	NE. 4.	NE. 3-4.
Air Temp.	47·0	42·0	43·0	49·0	53·2	56·0	56·9	53·0	50·5	46·0	45·0	43·8
Depth. Feet.												
0	41·8	41·9	41·4	41·8	42·2	41·8	42·1	42·3	42·3	42·4	42·5	42·4
25	...	...	...	41·5	41·9	41·5	41·7	42·1	42·0	..	42·2	42·2
100	41·6	41·4	41·4	41·3	41·3	41·3	41·4	41·8	42·0	42·2	42·2	42·0
200	41·6	41·4	41·4	41·2	41·3	41·3	41·3	41·5	41·9	42·2	42·1	42·2

Date	1905. Apr. 22.	1905. Apr. 23.	1905. Apr. 24.	1905. Apr. 25.	1905. Apr. 26.	1905. Apr. 27.	1905. Apr. 29.	1905. May 2.	1905. May. 3.
Time	2.35 p.m.	6 p.m.	5.45 p.m.	2.15 p.m.	10.45 a.m.	3 p.m.	2.15 p.m.	2.15 p.m.	2.30 p.m.
Position	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.	Yacht.
Wind	SW. 1.	N. 1-2.	WSW. 1-2.	WSW. ½.	E. ½.	Calm.	NE. ½.	W. 1.	NE. ½.
Air Temp.	51·3	42·2	43·1	47·0	50·1	46·0	48·0	50·0	45·0
Depth. Feet.									
0	42·7	42·3	42·3	42·4	43·6	44·3	44·0	44·0	43·0
25	42·3	...	42·3	42·4	42·4	43·3	43·0	43·0	42·8
100	42·2	...	42·1	42·1	42·0	43·0	42·8	42·8	42·8
200	42·2	42·1	42·0	42·0	42·0	42·0	42·6	42·7	42·6

XVII.—The Superposition of Mechanical Vibrations (Electric Oscillations) upon Magnetisation, and Conversely, in Iron, Steel, and Nickel. By James Russell.

(MS. received November 23, 1906. Read May 7, 1906. Issued separately February 28, 1907.)

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That mechanical vibrations affect magnetisation has long been known. The simple experiment of hammering an iron rod (Gilbert) in the earth's magnetic field needs only to be mentioned

About twenty years ago Ewing published investigations upon the effects of vibrations on magnetism.* These have been summarised in his subsequent work, *Magnetic Induction in Iron and other Metals.* He states (§ 84, 3rd ed.) that the "influence of vibrations and mechanical disturbances generally" "may be succinctly described by saying that vibration lessens those differences of magnetic condition to which hysteresis gives rise. Thus, if we tap a piece of iron during the application and removal of a magnetising force, we find at each stage of the application that tapping increases the susceptibility, and at each stage of the removal it reduces the retentiveness."

The effects of vibrations upon magnetism have in general been investigated by tapping. That is to say, vibrations have been superposed upon field (induction). But the effect of vibrations cannot be limited to one method of relative superposition of

* *Phil. Trans.*, 1885, p. 564.

vibrations and field. Change of field may be superposed upon continuously acting vibrations of uniform intensity for the time being. Moreover, if the tapping be described as "vigorous," it may be assumed that its effect upon magnetisation will have reached a limiting value. If, however, we wish to investigate the effect of vibrations within this limiting value, tapping the magnetic metal would afford a very imperfect method of so doing.

Many questions arise to which, so far as I know, no definite answers have been given.

For instance:—What is the effect of superposing vibrations upon magnetisation, relative to the effect of superposing magnetic change upon magnetic metals kept in a state of continuous vibration? What is the effect of superposing vibrations of various intensities at all stages of cyclic fields? If the vibrations be continuous, how does the energy loss during a magnetic cycle vary with maximum field, how with maximum induction? In what metal, or in what condition of that metal, is any given effect a maximum, or any given effect a minimum?

Further, it may well be asked whether the reduction of residual magnetisation by vibration is a necessary consequence of the molecular theory of magnetisation. In the present state of theoretical knowledge, would some such deduction as the following not be equally valid? Vibrations will give the molecular magnets intervals of freedom and allow them to assume more stable positions when the magnetic force is acting, so that when the force is withdrawn the residual magnetisation will be increased.

The above queries indicate the scope of the present investigation. They were in the first instance suggested by experiments upon the effects of electric oscillations on the magnetic properties of iron.* Little doubt existed in the mind of the author that the effects of mechanical vibrations would be found to be very similar to the effects of electric oscillations, provided that in the experimental methods employed the same distinction between the two methods of relative superposition of vibrations and field —the importance of which was insisted upon—also obtained.

Apparatus.

To obtain satisfactory quantitative measurements, the vibrations must be produced in such a way that they can readily be put "on" and "off," and that when on they remain constant in character and intensity. Such a result was very approximately attained by experimenting with wires attached to the gong of an ordinary electric bell of substantial construction. The wires were hooked at their ends, and one extremity of a wire could be linked into a small hole drilled near the edge of the gong, the other end being linked to the vertical arm of an L-shaped lever, either directly or, preferably, by means of a short length of thread. The latter method eliminates a possible source of uncertainty in the results due to minute torsional effects, which were much greater in

* "Notes on the Effect of Electric Oscillations (co-directional and transverse) on the Magnetic Properties of Iron," *Proc. R.S.E.*, vol. xxvi. p. 33, 1905.

annealed than in quenched nickel, negligible so far as observed in other cases. A weight of 11 ozs. suspended from the horizontal arm of the lever kept the wire from sagging, and made its contact with the gong such that the vibrations were transmitted to the thin wire supporting the weight with little apparent loss of intensity.

The dimensions and other particulars of the six wires used are given in the following table :—

Metal.	Condition.	Diameter.	Length.
Steel (mild).	Annealed.	·092 cms.	100 cms.
	Quenched.	·092 cms.	,,
Iron (not "soft").	Annealed.	·0907 cms.	,,
	Quenched.	·091 cms.	,,
Nickel (commercial).	Annealed.	·092 cms.	,,
	Quenched.	·0909 cms.	,,

The three wires were annealed in a horizontal position normal to the earth's field, at a red heat, by passing a Bunsen flame slowly along their entire length. The other three wires, cut from the same hanks, were heated to redness by an electric current, and quenched by plunging in water a moment after the current was broken.

An exploring coil was wound on the central portion of a glass tube 41 cms. long and 0·8 cm. bore. Another glass tube of the same length but of greater diameter surrounded that of smaller bore and supported a magnetising coil of two layers of copper wire. This arrangement was adjusted in position so that the wire, supported at one end by the gong and at the other end by the lever as above described, coincided with the axis of the concentric tubes at right angles to the earth's magnetic field.

The exploring and magnetising coils were each in series with one of two solenoids concentrically wound, so connected and adjusted that, before the magnetic wire was introduced, the maximum current produced no motion of the more delicate of the two ballistic galvanometers used.

The accessory apparatus was such that all the operations could readily be performed, and readings of the galvanometer accurately taken, without the assistance of a second observer.

The Effect of the Load.

The weight (11 ozs.) used throughout the experiments subjected each wire under test to a pulling stress not greater than 0·5 kilo. per sq. mm. of sectional area. The four tables submitted show the effects of this load upon magnetisation.

Annealed Steel.			Quenched Steel.		
16/3/06. H	Without Load. B_o	With Load. B_L	18/3/06. H	Without Load. B_o	With Load. B_L
·27	142	148	·45	100	105
·42	252	258	·95	260	270
·78	594	630	1·15	345	352
1·02	915	1000	1·50	515	520
1·22	1420	1640	2·18	1000	1030
1·46	2742	3310	2·93	1960	2035
1·81	6050	6900	3·83	3390	3460
3·20	12880	12940	5·57	5620	5760
4·85	14520	14600	7·62	7460	7580
5·73	15000	14930	8·75	8105	8250
Annealed Nickel.			**Quenched Nickel.**		
21/3/06. H	Without Load. B_o	With Load. B_L	22/3/06. H	Without Load. B_o	With Load. B_L
·26	40	34	1·13	38	36
·62	122	91	1·50	51	45
1·06	348	200	2·17	123	94
1·27	592	284	3·9	257	224
1·86	1560	697	5·8	353	329
3·65	2936	1900	8·18	510	465
5·44	3610	2660	9·45	890	626
7·48	3900	3080	14·0	2330	2150
8·50	4050	3280	23·2	3200	3060

After annealing or quenching, as the case may have been, the wires were, by means of a revolving commutator, demagnetised by decreasing reversals without load, after which the measurements given under columns B_o were obtained. Each measurement is one-half of the average induction change obtained ballistically on the 30th and 35th (+ and − respectively) reversals of the magnetising force H.

The wires were again demagnetised and then linked between the electric bell and the L-shaped lever, which operation puts on the load. By intermittent pressure on the lever the load was virtually put "off" and "on" twelve times. The wires were again demagnetised by decreasing reversals, and the measurement given under columns B_L (induction with load) taken, the same routine being observed as before. H, B_o, and B_L are in C.G.S. units.

It will be noticed that the effect of the load to increase magnetisation is greater for annealed than for quenched steel, and that in the former condition only has the Villari critical point just been reached. Annealed and quenched iron exhibit respectively similar although somewhat less differences, and for this reason the readings have not

been tabulated. On the other hand, the effect of the load in decreasing magnetisation in nickel is very much greater in the annealed than in the quenched condition.

Note on the Effect of Torsion.—When the annealed nickel wire was linked directly to the lever, and not by means of a thread, as is here the case, the effect of the load to reduce the magnetisation was less. The load curve might even exceed the normal curve without load for a short distance where $d\mathrm{B}/d\mathrm{H}$ was greatest. I could trace this rise to no other source than a minute torsional effect which disappeared entirely when the method of connecting the wire eliminated such a possibility. The effect could be reproduced in an exaggerated form by twisting the wire a very few degrees per 100 cms. of length.

Strictly speaking, therefore, the experimental results are based upon the effects of vibrations upon that particular condition which has been reached by subjecting the magnetic metals first to annealing and then to demagnetisation by decreasing reversals with a load not exceeding 0·5 kilo. per sq. mm. of sectional area, the load remaining on throughout the experiments. It may be observed that, while load may either increase or decrease permeability, the effect of vibrations is always to increase permeability.

A few experiments were made in which the wires were soldered to the gong and no load used. These will be referred to later.

Superposition of Vibrations and Field.

The importance of the order and manner in which mechanical vibrations and field (magnetisation) may be superposed the one upon the other has already been mentioned. The order of superposition is distinguished in the same way in which the superposition of electric oscillations and field was distinguished in the paper already referred to.

A. Mechanical vibrations are superposed upon constant field.

B. A change of field is superposed upon mechanical vibrations permanently acting.

Experimental Methods under *A* Conditions.

After demagnetisation by decreasing reversals (the revolving commutator being in all cases used), the field is put on by steps of increasing reversals,* followed by thirty to thirty-five reversals of the pre-arranged field maximum. One-half the average of two consecutive galvanometer readings determines the value of the induction at this field maximum. Single steps (the first being zero) are then taken from the fixed maximum to a sufficient number of points all round the normal loop. At each point, mechanical vibrations are superposed by simply ringing the electric bell. This *necessitates demagnetisation*, followed by thirty reversals of the maximum field value after each step taken and before the next observation is made.

Two curves result from the galvanometer readings taken during this process. The

* This process tends to preserve the symmetry of the loops with reference to the origin.

first is the B – H hysteresis loop determined by what is virtually EWING's method of single steps from a maximum. The second measures the instantaneous change of induction which takes place when mechanical vibrations are superposed at any and all stages of the normal cycle.

EXPERIMENTAL METHODS UNDER *B* CONDITIONS.

After demagnetisation as before, the mechanical vibrations are put on. They remain "on" until any set of readings has been completed. Under these conditions the usual curves showing either the relationship between H and B or the B – H hysteresis loops are determined, as the case may be. In the former case, one-half the average induction change on the 30th and 31st reversals determines the value of B, commencing in the usual way with the lowest values of H, and finishing with the highest. In the latter case, the loops are determined by what is now exactly EWING's method of single steps from a fixed maximum. The area enclosed by this loop, like the normal cycle above described, and with which it is compared, measures the energy loss per cycle, when the properties of the magnetic metal are altered by permanently acting mechanical vibrations. It is hardly necessary to point out that the loop delineating the instantaneous changes due to superposed vibrations under the *A* conditions does not do so.

DIAGRAMS.

The experimental results are shown in the diagrams. The abscissæ are in all cases values of H in C.G.S. units. The ordinate values of B are likewise in C.G.S. units. In those figs. (III., IV., V., XII., XIII., XIV.) where ratio ordinates also occur, the ratio values are on the left, those of B on the right.

It was found, on plotting the diagrams, that the observations with vibrations fell as readily into line as when no vibrations were acting. When the fields are cyclic, each arm of the loops is obtained by plotting the average readings taken on both arms. This secures symmetry of the diagrams in reference to the origin.

INTENSITY OF VIBRATIONS, VARIED.

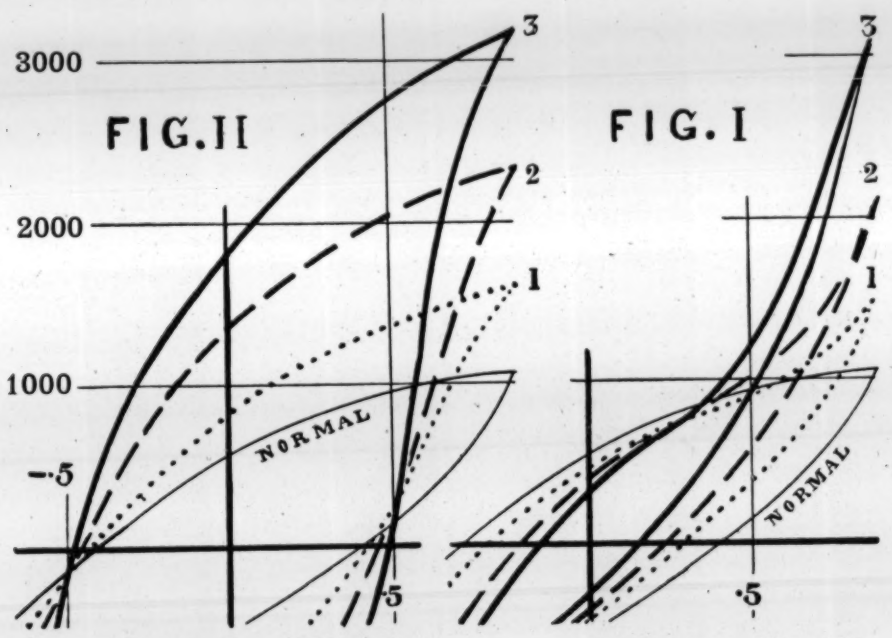
The intensity of the vibrations could be increased by increasing the voltage at the terminals of the electric bell. When the voltage was too great, the fundamental note of the bell was entirely lost in the louder rattle of the hammer, and the tingling sensation felt by the fingers on touching the vibrating wire was markedly reduced. In the following experiments the musical note of the gong was not overpowered in this way even with the highest voltage used.

Figs. I. and II. show, for annealed iron and for one low value of field ($H = 0{\cdot}92$), the cyclic results obtained under the *A* and *B* conditions respectively, for three different in-

tensities of mechanical vibrations. The normal cycles are the same in both cases. The other curves show the effect of increasing the intensity of vibrations in the ascending order indicated by the numerals 1, 2, and 3. The induction reached at cyclic extremes is greater, the greater the intensity of vibrations, irrespective of the order of superposition.

It may be noted, however, that one-half the average induction change with vibrations permanently acting (fig. II.) is in all three cases a little greater than the induction reached when vibrations are superposed at the limit of the normal cyclic obtained without vibrations (fig. I.).

As the cyclic extremes are departed from, a glance at the curves shows that the



CURVES 1.2.3. WITH VIBRATIONS OF INCREASING INTENSITY

order of superposition under the *A* and *B* conditions produces apparently very different results.

A *Conditions.*—The induction change due to superposed vibrations is greater with increasing field, and is always in the same direction as the field change; but if the field be decreasing the induction change due to vibrations is first against, afterwards with, the field change. Increase of the intensity of vibrations thrusts the neutral point towards the vertical axis, producing at the same time a progressive collapse of the two arms of the loops.

B *Conditions.*—For any given intermediate value of cyclic field, the rate at which induction is changing is progressively increased with vibrations of increasing intensity. But the rate of magnetic change always remains greater with increasing than with decreasing field. Hence the areas of the loops (energy loss per cycle) progressively increase with vibrations increasing in intensity.

A *and* B *Conditions.*—If the cyclic field be not unduly increased, the curves cross each other under the *A* conditions when both field and induction are decreasing, but under the *B* conditions when both field and induction are increasing. They cross the vertical and horizontal axes in inverse order under the two conditions of relative superposition of vibrations and field. Consequently, under the *A* conditions residual magnetisation and coercive force are progressively decreased, but under the *B* conditions progressively increased, with increasing intensity of vibrations.

Note, however, that if the cyclic field were sufficiently increased the increase of induction at cyclic extremes would nearly vanish, and in all probability the loops would be progressively decreased with vibrations of increasing intensity. In all probability also the curves would cross the vertical and horizontal axes in the same order as they do under the *B* conditions.

Experiments, however, were not continued in this direction ; indeed, the vibrations were varied more for the purpose of determining the most suitable intensity to use throughout the experiments now to be described, than for completely investigating the effects of such variations at all stages of magnetisation.

Intensity of Vibrations, Constant (pages 498 to 508).

We now pass on to consider the effects of vibrations, not when their intensity is varied, but when the field and consequent magnetisation are varied, the intensity of vibrations remaining the same. The three magnetic metals are all tested in this way, both in the annealed and in the quenched condition.

The strongest vibrational intensity, corresponding to curves 3 of figs. I. and II., is now used throughout.

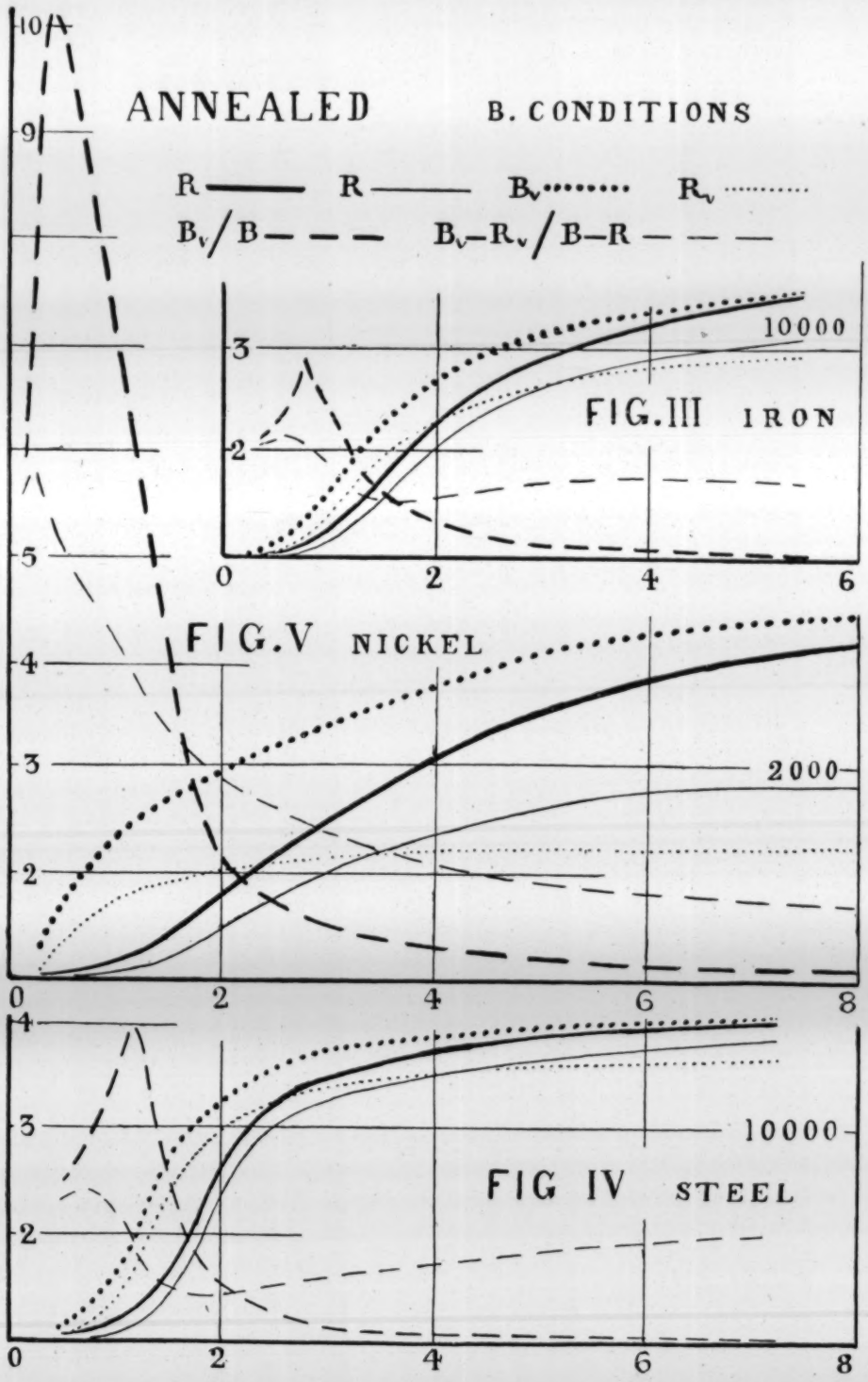
Annealed Metals, B *Conditions.*

Permeability and Retentivity Diagrams.—Figs. III., IV., and V. show, for the annealed condition of iron, steel, and nickel respectively, the usual B, H curves obtained in the manner already described, also curves of residual magnetisation (likewise plotted against H) obtained by withdrawing the field at all values of the induction measured. The full and faint continuous lines are the normal induction and the normal residual magnetisation curves respectively without vibrations. The full and faint dotted lines are the induction and residual magnetisation curves respectively with permanently acting vibrations.

The full and faint dash curves show the ratios B_v/B and $B_v - R_v/B - R$ respectively, for all values of H. B and R signify the induction and residual magnetisation without vibrations ; B_v and R_v, the induction and residual magnetisation with vibrations.

The ordinates and abscissæ (H) are drawn to the same scale in the three figs., except that the scale of the ordinates for the permeability and retentivity curves in fig. V. (nickel) have been increased five times. The values of the ratio ordinates

(B_v/B and $B_v - R_v/B - R$) are to the left, the values of the induction ordinates to the right. It may be repeated that H and B are in C.G.S. units in all the diagrams.



EXPERIMENTAL RESULTS.

Permeability.—Permanently acting vibrations increase permeability. B_v/B is approximately a maximum when dB_v/dH is a maximum. But the actual difference

$B_v - B$ is not a maximum until, on the further increase of H, the maximum value of dB/dH is more nearly approached.

In the former case the increase is much greater in nickel than in either iron or steel. In nickel, the maximum value of $B_v/B = 10$, while in iron and steel it is only about 3 and 4 respectively. As H passes beyond these values, B_v/B rapidly falls, and in sufficiently strong fields approximates to unity (strong dash-line curves).

In the latter case the actual maximum difference $(B_v - B)$ is greatest in steel (4500), less in iron (2300), least in nickel (1250). It should be noted that the steel is more permeable than the iron wire used.

Residual Magnetisation in Relation to Field. — Permanently acting vibrations increase or decrease residual magnetisation as the fields are low or high. Both these effects are greatest in annealed nickel.

When the field is sufficiently increased, the induction and retentivity curves are always in the following descending order: B_v or B, R, R_v. This final relationship is very marked in annealed nickel, much less so in iron, least in steel.

It is instructive to consider, not merely the residual magnetisation, but the ratio of the negative induction changes with and without vibrations when the field is withdrawn $(B_v - R_v/B - R)$. In this way a ready comparison may be made with relative positive induction change with and without vibrations when the field is acting (B_v/B).

The effect of vibrations in increasing the negative induction change in low fields when H is withdrawn is much greater in annealed nickel than in either iron or steel. In nickel (faint dash-line curves), the maximum value of $B_v - R_v/B - R = 5{\cdot}8$, while in iron and steel it is only 2·2 and 2·6 respectively. These maxima occur at or near the lowest field values used. As H is somewhat increased these ratios rapidly fall in all the three metals. In nickel, as H is further increased this fall takes place slowly, and continues to do so at the maximum value of field used, viz. $H = 15$.

In iron and steel, on the other hand, these ratios increase in value when the field is higher than about 2 C.G.S. units.

Consequently, in annealed nickel, $B_v - R_v/B - R$ is much greater in low than in high fields. In iron and steel, on the other hand, this difference is comparatively small.

The faint dash-line curves show the comparative results fully.

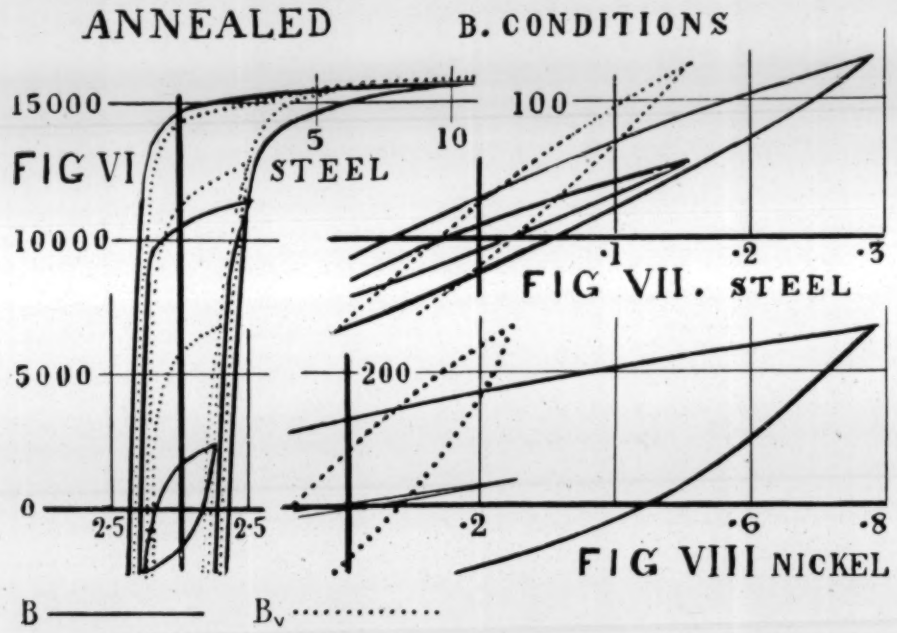
Residual Magnetisation in Relation to Induction. — If R and R_v be plotted against B and B_v respectively, it is seen that the residual magnetisation is less with than without permanently acting vibrations, when the field supporting the same induction in both cases is withdrawn. This decrease is greatest in annealed nickel.

See results under the same conditions for quenched nickel (p. 506).

Cyclic Diagrams.—Figs. VI., VII., and VIII., taken in conjunction with fig. II. for iron (curve 3 having the same intensity of vibrations as now used), show the changes in the hysteresis loops when a cyclic field is superposed upon permanently acting vibrations

in the manner described on p. 496. The dotted and continuous lines represent the cycles with and without vibrations. Figs. VI. and VII. show, for annealed steel, loops with and without vibrations, corresponding to the following four maximum values of field, viz. H = 0·16, 1·46, 2·6, and 11·0. The induction at cyclic extremes covers the wide range between B = 56 and B = 15,750 without vibrations. These loops are typical of others taken at intermediate values of field. The cyclic curves for annealed iron are essentially similar to those for annealed steel (see fig. II., curve 3).

In figs. VII. and VIII. the smaller and larger of the two continuous-line loops (without vibrations) enable comparison to be made with the dotted-line loops (with vibrations)



for the same value at cyclic extremes of field and induction respectively. Fig. VII. is for annealed steel, fig. VIII. for annealed nickel.*

EXPERIMENTAL RESULTS.

Coercive Force.—Permanently acting vibrations increase coercive force when the values of field are low. This effect soon disappears as the fields are taken higher, and thereafter vibrations decrease coercive force. For the same value of induction, coercive force is always decreased.

* Fig. VIII. is one of the earlier experiments, and a thread was not introduced between the lever and the nickel wire under test. These observations have been repeated with this alteration, and the larger loop ought to be more sheared over than shown in this figure. The coercive force remains the same, the residual magnetisation is reduced to within 15 C.G.S. units of the dotted loop, and the value of H is increased to 1·25. These corrections give the values of R and B at the cyclic extreme the same as in fig. V. for the same value of field. The increase of permeability and residual magnetisation is due to a *minute* torsional stress imparted to the nickel wire when no thread is introduced. The two smaller loops with and without vibrations remain exactly as shown, as also fig. XI., p. 503. The experimental results, therefore, relative to coercive force and hysteresis loss, remain as stated in the following section.

At low inductions and in low fields the decrease and the increase of coercive force respectively are both enormously great in annealed nickel as compared with iron or steel.

Hysteresis Loss in Relation to Field.—Permanently acting vibrations increase hysteresis loss in low fields, diminish hysteresis loss in high fields. The former is relatively the larger effect. In iron and steel the increase becomes less if the field be unduly decreased, the ratio then being about two to one. In nickel, on the other hand, the increase of hysteresis loss in similarly low fields of the order of $H = 0{\cdot}2$ units is enormous. Fig. VIII. shows that the hysteresis loss with vibrations must be about twenty times as great as when no vibrations are acting.

As the fields are increased, however, the increase and final decrease of energy loss with vibrations in the three metals become quite compatible with each other.

Hysteresis Loss in Relation to Induction.—When the induction at cyclic extremes is the same, permanently acting vibrations cause a diminution of energy loss per cycle in the three magnetic metals at all values of induction. For moderately small inductions the decrease is approximately the same as that in my previous paper for iron with electric oscillations (say about three times). As the induction is increased, the diminution of energy loss becomes relatively less.

When, however, the induction is further decreased than above indicated, the decrease of energy loss is much greater in annealed nickel (see fig. VIII., where the induction at cyclic extremes is $B = 260$). In iron or steel, on the other hand (see fig. VII., where the induction at cyclic extremes is $B = 127$), the decrease of energy loss is less than at somewhat higher inductions, thus making the relative difference between nickel and either iron or steel more marked at these low induction values.

Annealed Metals, A *Conditions.*

Cyclic Diagrams.—Figs. IX., X., and I. show for iron, and fig. XI. for nickel, the effects of superposing vibrations under the *A* conditions. The dash-line curves measure the instantaneous induction change which occurs when vibrations are superposed at all stages of the normal loops (continuous-line curves). Figs. IX. and X., for iron, are for low and high cyclic induction values respectively, fig. I. for an intermediate value. The curves for steel are not given, as they are essentially similar.

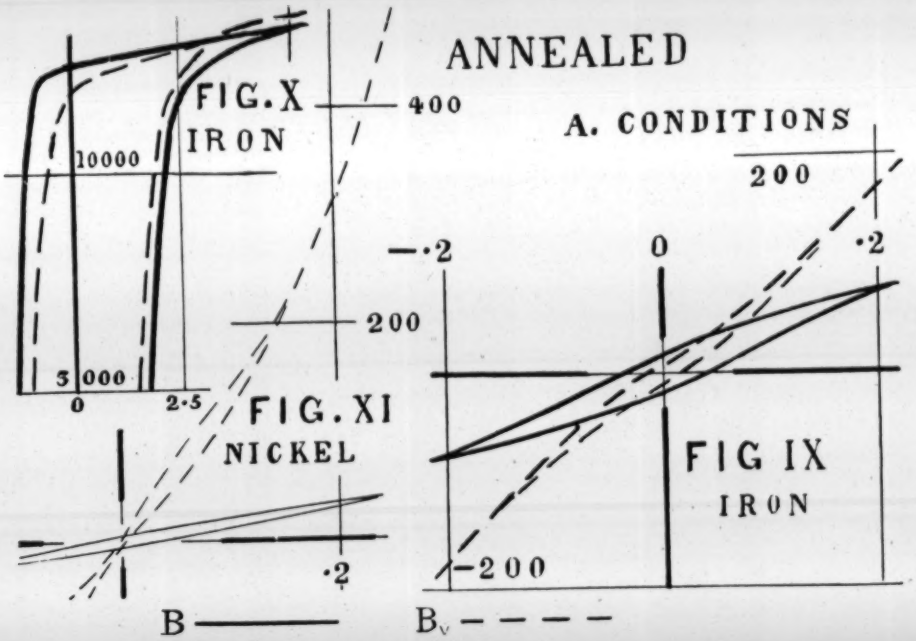
EXPERIMENTAL RESULTS.

The superposition of vibrations at cyclic extremes produces, for all values of field, an increase of induction. In high fields B_v/B approximates to unity.

The increase is enormous in nickel when field is sufficiently reduced. When $H = 0{\cdot}2$, $B_v/B = 13$ (fig. XI.). In iron and steel this large increase in low fields is entirely absent (fig. IX.).

In nickel, the induction reached is much greater when vibrations are superposed (*A* conditions) than one-half the induction change on reversals when vibrations are permanently acting (*B* conditions). Compare figs. XI. and VIII. As we have seen, the reverse holds for iron and steel. Compare figs. I. and II. No systematic investigation, however, was made as to how these relative effects, under the *A* and *B* conditions, may vary through wide ranges of field, in nickel as compared with iron or steel.

As the cyclic extremes are departed from, the induction change which occurs when vibrations are superposed follows the field, not the field change. This effect, however, is a decreasing one, and a point is reached when the field is decreasing where superposed vibrations produce no induction change whatever.



It should be noted that, unless demagnetisation precedes each observation (*A* conditions), thus wiping out the effects of the immediately preceding superposition of vibrations, it is highly improbable that any induction change, opposite in sense to the field change, would be observed. For instance, if, as in EWING'S experimental method, field change and vibrations alternated all round the loop, the possible induction change would be exhausted on the up-curve at or near the cyclic extreme; and since the effect is a decreasing one, no induction change opposing the field change would be obtained with the same or any less intensity of vibrations when the cyclic extreme is departed from.

When this neutral point is passed, the superposition of vibrations produces induction change, in the same sense as the field is changing, and continues to do so until the first conditions are reverted to at the other cyclic extreme.

In low fields the neutral point occurs close to the vertical axis (fig. IX. for iron, fig. XI. for nickel). In high fields it is thrust from the vertical axis, and towards the

cyclic extremes (fig. X. for iron). Fig. I. shows an intermediate position at moderate values of field and induction.

But the position of the neutral point also depends, as we have seen (p. 497), upon the intensity of the vibrations, and it is now apparent that the shift of the neutral point depends upon the relative intensity of vibrations and cyclic field (induction). Unless possibly when the normal cyclic induction is extreme, increase (decrease) of cyclic field has the same effect as decrease (increase) of vibrational intensity in thrusting the neutral point from (towards) the vertical axis.

In all cases the induction change is greatest when mechanical vibrations are superposed on an increasing field. For low fields this occurs at or near cyclic extremes, where the slope of the curves is greatest. But as the cyclic field maxima are increased, the greatest induction change occurs at an earlier stage of the increasing field, where in this case also the normal curves are steepest.

Quenched Metals, B *Conditions.*

Permeability and Retentivity Diagrams.—Figs. XII., XIII., and XIV. show, for the quenched condition of iron, steel, and nickel respectively, the usual permeability and residual magnetisation curves with and without permanently acting vibrations, in the same way as figs. III., IV., and V. show these curves for the annealed condition. The corresponding ratio curves are also given. The scale of the horizontal ordinates of fig. XIV. has been diminished three times as compared with fig. V., on account of the lower permeability of quenched nickel.

The effects of quenching the three metals in water from a red heat may be noted by comparing the full (B) and faint (R) continuous-line curves of figs. XII., XIII., and XIV. with the corresponding curves of figs. III., IV., and V., for the annealed condition of these metals. We are not, however, concerned with the effect of quenching, but with the effect of mechanical vibrations upon the quenched condition.

EXPERIMENTAL RESULTS.

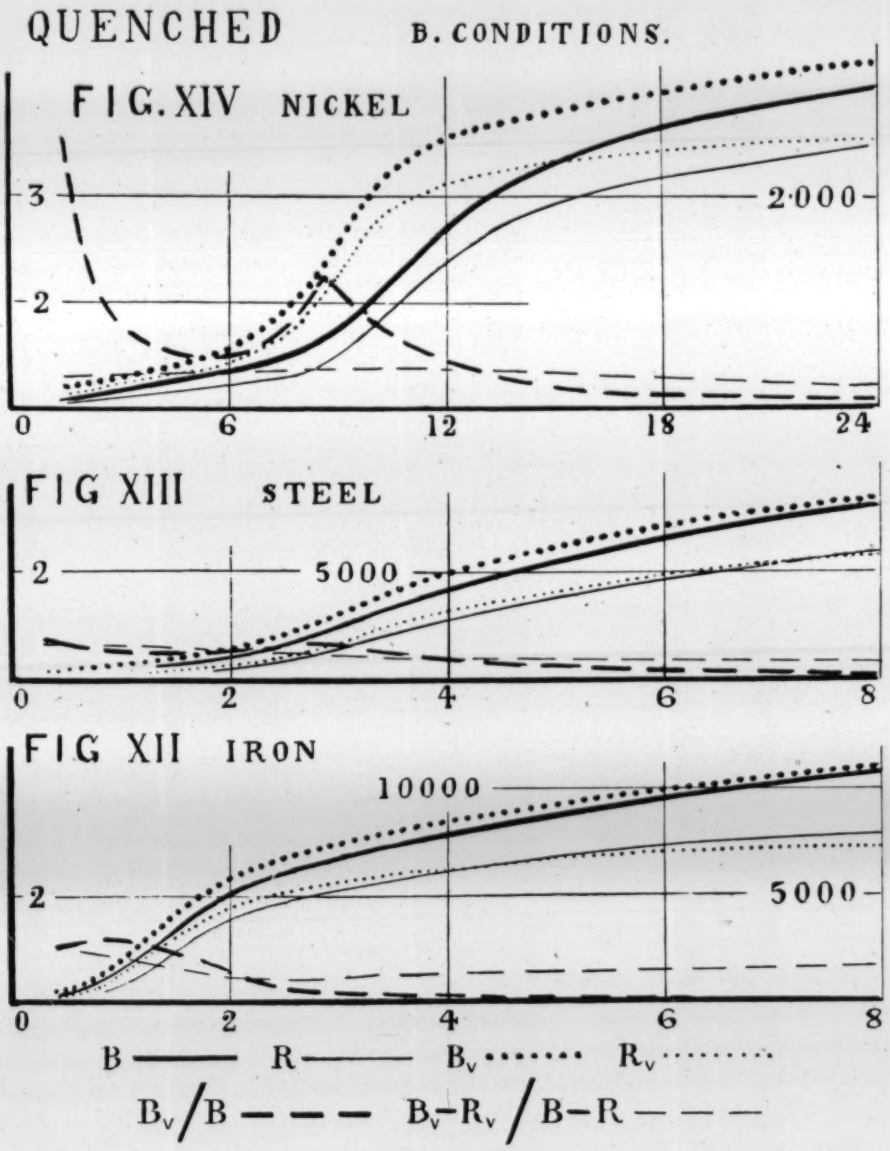
Permeability.—The effect of permanently acting vibrations in increasing permeability is very much reduced in quenched as compared with annealed iron and steel. The reduction of the ratio B_v/B is somewhat more marked in quenched steel than in quenched iron (figs. XII. and XIII., full dash-line curves).

In quenched nickel, on the other hand, the full dash-line curve B_v/B (fig. XIV.) shows the existence of two maxima, the second where dB_v/dH is a maximum. In another series of experiments both maxima approximated to $B_v/B = 3$, and in lower fields than here shown the ratio fell as in the annealed metals. In quenched steel corresponding maxima are just indicated. Quenched iron shows, like the annealed metals, one maximum where approximately dB_v/dH is greatest.

Further, the increase of permeability with vibrations is very much greater in quenched

nickel than in quenched iron and steel. In this respect quenched nickel more nearly resembles the annealed metals.

The observations from which these curves were plotted show that $B_v - B$, as in the annealed metals, does not reach a maximum until H is further increased. In nickel, $B_v - B$ is a little greater than in either iron or steel (1000 as against 700). In the annealed metals the opposite was the case.



Residual Magnetisation in Relation to Field.—Permanently acting vibrations increase or decrease residual magnetisation as the fields are low or high; but the former effect is very much less in quenched iron and steel than in quenched nickel. This accounts for the fact that in quenched iron and steel the retentivity curves with vibrations (R_v) never rise above the normal induction curves without vibrations (B), as they do in the annealed metals and in quenched nickel.

When the field is sufficiently increased, the induction and retentivity curves for quenched iron and steel occur in the same descending order as in the annealed metals: B_v or B, R, R_v. The field has not been carried high enough to show with certainty whether this final relationship occurs in quenched nickel.

Consider now the ratio of negative induction change $(B_v - R_v/B - R)$ with and without permanently acting vibrations. This ratio does not differ much from 1·2 to 1·4 for all the three metals in a quenched condition for all values of field; but in the additional experiments referred to in the preceding page this ratio for quenched nickel increased as the field was decreased below $H = 3$.

Retentivity in Relation to Induction. — Permanently acting vibrations do *not* decrease retentivity in all the quenched metals and at all values of induction, as is the case, so far as observed, in the annealed condition of the same metals (see p. 500).

In quenched nickel the residual magnetisation is decidedly greater with than without vibrations for low values of induction. For inductions under 500 or 600 the increase of retentivity with vibrations is relatively great. The cyclic curves of fig. XVI. may also be referred to. The residual with vibrations (dotted curve when $H = 0$) is substantially greater than the residual without vibrations (stronger full-line curve when $H = 0$), the maximum induction before the field is withdrawn being in both cases 180 C.G.S. units.

For inductions ranging between 1000 and 3000 no certain conclusion was reached. Fig. XVII. shows the residual with vibrations to be greater (by 20 magnetic lines) than the residual without vibrations, the induction in both cases being 2400. On the other hand, another experiment made at a different time, with an induction in both cases of 2230, showed the residual to be less (by 6 magnetic lines) with than without vibrations.

In any case, no doubt exists that in quenched nickel the residual magnetisation is greater with than without permanently acting vibrations when the field producing in both cases the same induction of the order of hundreds is withdrawn; further, that at the highest inductions used (3000 to 4000) the decrease of residual magnetisation with vibrations, if it exists, is very small.

In quenched steel, on the other hand, permanently acting vibrations decrease the residual magnetisation for all values of induction.

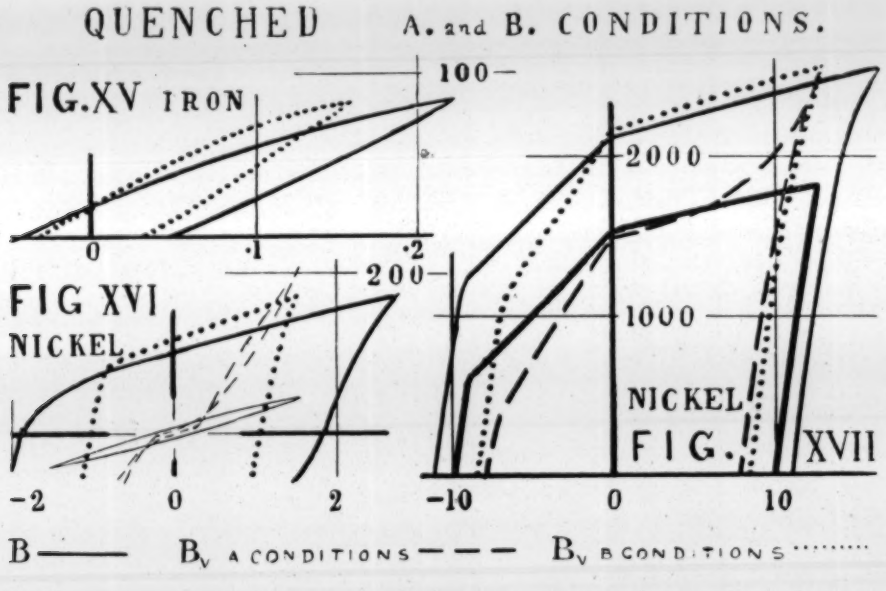
For low values of induction, quenched iron takes an intermediate position. For the same maximum induction, with and without vibrations, the residual magnetism is the same. This is shown in fig. XV., where the maximum value of $B = 85$. But as the induction is taken higher, permanently acting vibrations increasingly decrease residual magnetisation.

Cyclic Diagrams.—Figs. XVI. and XVII. show the effects both of permanently acting and superposed vibrations for quenched nickel in low and higher cyclic fields respectively. The continuous-line curves are the normal hysteresis loops for two values of field in each figure. The dash-line curves measure the instantaneous induction change when

vibrations are superposed (*A* conditions) at all stages of the smaller of the normal loops (lower field). The dotted loops, on the other hand, measure the hysteresis loss for permanently acting vibrations (*B* conditions) for the same maximum value of field (compare with the smaller normal loops in each figure), and also for the same maximum value of induction (compare with the larger normal loops in each figure).

Fig. XV. shows the effect of permanently acting vibrations only for quenched iron upon hysteresis loss (and residual magnetisation for the same maximum value of induction (B = 85) already referred to). The dotted and full-line curves have the same signification as before.

Attention may here be called to the shape of the loops in the case of quenched nickel. The areas are bounded practically by six straight lines, rather more marked



when the induction is of the order of thousands (fig. XVII.) than hundreds (fig. XVI.). The abrupt changes which occur during the cyclic process may be compared with those first observed by NAGAOKA * when nickel wire is subjected to torsion combined with longitudinal pull. The same abrupt changes were obtained without load.

Note that vibrations have little or no effect in lessening the rectilinear character of the normal loops. Indeed, for low values of field, vibrations rather increase this characteristic than otherwise.

Coercive Force.—The general effect of permanently acting vibrations is the same in the quenched as in the annealed condition, and the same differences also exist when quenched nickel is compared either with quenched iron or steel. These latter metals call for no further remark. Their behaviour is normal. But the decrease of coercive force for the same value of low induction is less in quenched than in the annealed

* *Magnetic Induction in Iron*, EWING, 3rd ed., p. 248 ; *Jour. Coll. Science Imp. Univ. Japan*, vol. ii. p. 304.

nickel. On the other hand, its increase for the same maximum value of low field is greater in quenched than in annealed nickel. Compare figs. XVI. and VIII.

Hysteresis Loss.—The same general conclusions applicable to the annealed condition also apply to the quenched condition of the three metals. Iron and steel call for no special remark. In quenched nickel the increase of hysteresis loss caused by permanently acting vibrations for the same value of low field is (as in annealed nickel) enormously greater than in iron and steel. On the other hand, for the same value of induction, the reduction of hysteresis loss caused by vibrations is very much less in quenched than in annealed nickel. In both cases figs. XVI. and VIII. (annealed nickel) may be referred to.

Quenched Metals, A *Conditions.*

EXPERIMENTAL RESULTS.

The superposition of vibrations at all stages of the normal hysteresis loop produces the same general effects in the quenched as in the annealed condition of the three metals. But in quenched nickel a striking peculiarity is found to exist. The neutral point is not so well defined as in the annealed condition of the three metals, and in quenched iron and steel. When this point is reached, the increase of induction has disappeared, but the decrease of induction is very small until the field has passed through zero and has changed sign. This is shown in figs. XVI. and XVII. It will be observed that, when the increase of induction has disappeared, the dash-line curves bend sharply towards the vertical axis, thus closely hugging the normal loop for some distance. Fig. XVII. shows that, when the cyclic induction is considerable, the decrease of induction due to superposed vibrations becomes almost immediately and increasingly well marked after the field supporting the normal loop has changed sign. On the other hand, when the cyclic induction is small (fig. XVI.) the dash-line curve still hugs the normal loop for some distance after the field has been reversed. The dash-line curves of fig. XVI. may be contrasted with fig. XI. for annealed nickel.

Superposed vibrations, therefore, have relatively very little effect in reducing residual magnetisation in quenched nickel. It is interesting to compare this result with that recently obtained by Prof. ANDREW GRAY.* He found that vigorous tapping at the temperature of the room had no effect in reducing the residual magnetisation of a rod of a certain sample of HEUSLER's magnetic alloy, although previous tapping at the temperature of 100° produced a considerable reduction in the residual magnetisation. It is obvious that quenched nickel approximates closely to this magnetic alloy, in resisting the usual effect of vibrations to lower residual magnetisation, whether superposed under the *A* or *under the B conditions.* But in the latter case vibrations increase residual magnetisation at low inductions (see p. 506).

* "Note on Heusler's Magnetic Alloy," *Proc. Roy. Soc.*, vol. lxxvii., Series A, p. 256.

Summary of Experimental Results.

Vibrations may be superposed upon constant field (*A* conditions), or change of field may be superposed upon permanently acting vibrations (*B* conditions).

A *and* B *Conditions.*

Permeability.—In all cases vibrations increase induction. In high fields B_v/B approximates to unity. The relative magnitude of this effect under the *A* and under the *B* conditions depends upon the magnetic metal and possibly on the field intensity. In nickel, the induction reached is greater (if field be not unduly increased) when vibrations are superposed (*A* conditions) than one-half the induction change on reversals when vibrations are permanently acting (*B* conditions). The reverse is the case for iron and steel.

B *Conditions.*

Permeability.—In all cases B_v/B is approximately a maximum when dB_v/dH is a maximum. In annealed nickel the maximum value of $B_v/B = 10$; in annealed iron and quenched nickel, about 3; in annealed steel, 4; and in quenched iron and steel, a decided minimum. In quenched nickel the B_v/B curve shows two well-marked maxima: the second when dB_v/dH is a maximum, the first at a lower value of field. Two corresponding maxima are merely indicated in quenched steel. In no other case are they observable.

On H being further increased, maximum values of $B_v - B$ occur, so far as observed, a little earlier than maximum values of dB/dH. In annealed steel the maximum value of $B_v - B = 4500$; in annealed iron, 2300; in annealed nickel, 1250; but in quenched iron and steel rather less (700) than in quenched nickel (1000).

Negative Induction Change.—The ratio of the negative induction change when field is withdrawn, with and without vibrations ($B_v - R_v/B - R$), distinguishes the quenched from the annealed condition. In the quenched metals this ratio does not differ greatly from 1·3 for all values of field other than the lowest. In the annealed metals, on the other hand, it varies largely with field, reaching a maximum in annealed nickel (5·8), and minimum values (1·6) in annealed iron and steel, when H is approximately = 2. (In quenched iron a corresponding minimum is merely indicated.) In nickel $B_v - R_v/B - R$ is much greater in low than in high fields. In annealed iron and steel this difference is less marked. In all cases and in the lowest fields used $B_v - R_v/B - R$ approximates to B_v/B.

Coercive Force, Retentivity, and Hysteresis Loss in Relation to Field.—These are increased or decreased as the field is low or high, but in quenched nickel the decrease of residual magnetisation, if it exists at all, is very small.

The relative increase of coercive force is greater in annealed and quenched nickel than in iron and steel. Increase passes into decrease earlier in the case of coercive force than of residual magnetisation.

The increase of hysteresis loss in low fields is relatively greater than its decrease in high fields. In annealed and quenched nickel its relative increase is enormously great in the lowest fields used. There is nothing corresponding to this when field is unduly decreased in iron and steel.

Coercive Force and Hysteresis Loss in Relation to Induction.—In all cases for the same value of induction at cyclic extremes, coercive force and hysteresis loss are decreased. At high inductions the decrease of energy loss is relatively smaller than at lower inductions. At very low inductions the decrease of loss produced by vibrations is a decided maximum in *annealed* nickel.

Retentivity in Relation to Induction.—Vibrations do not in all cases decrease residual magnetisation. In quenched nickel, when the field producing the same induction of the order of hundreds in both cases is withdrawn, the residual magnetisation is greater with than without permanently acting vibrations. At low inductions in quenched iron R_v may equal R; in all other cases R_v is less than R.

The effect of permanently acting vibrations in reducing residual magnetisation at high inductions is greater in annealed nickel than in annealed or quenched iron and steel. In quenched nickel this effect, if it exists at all, is very small.

A *Conditions.*

When vibrations are superposed at all points of the normal hysteresis loop, the induction change as the cyclic extremes are departed from is first against, afterwards with, the field change. The position of the neutral point depends upon the relative intensity of vibrations and cyclic field (induction). The smaller the cyclic field and (so far as my experiments have gone) the greater the vibrational intensity, the closer is the neutral point thrust towards the vertical axis; the higher the cyclic field and the less the vibrational intensity, the closer is the neutral point thrust towards the cyclic extreme. Thereafter the induction change continues to follow the field change until the other cyclic extreme is reached.

In all cases the induction change is greater when vibrations are superposed on the normal loop when the field is increasing. For low fields the maximum change occurs at or near cyclic extremes, where the slope of the curve is greatest. But as the cyclic field is increased, the maximum induction change occurs at an earlier stage of the increasing field, where in this case also the normal curve is steepest.

Vibrations of increasing intensity produce a progressive collapse, by no means complete, of the two arms of the loops. The imperfect nature of this collapse is well exhibited in quenched nickel in low fields. The curves cross at two points, three loops being thus formed. This peculiarity is not confined to quenched metals.

Magnetic Hysteresis.

When field varies cyclically, the loop formed by the curves connecting B and H is said to be the result of *magnetic hysteresis*; no loop, no hysteresis.

The effect of vibrations superposed at all stages of the normal loop (*A* conditions) is, generally speaking, to lessen those differences of magnetisation to which hysteresis *without vibrations has already given rise.*

But if the vibrations continue, and the field becomes cyclic, the effects of vibrations cannot be stated concisely in terms of the effects of magnetic hysteresis. To do so, when cyclic field is superposed upon permanently acting vibrations (*B* conditions), requires as complete a knowledge of the B, H loop as is required without vibrations.

The loops obtained when vibrations are permanently acting (*B* conditions) are stable to subsequent "offs" and "ons" of the same vibrations. The loops obtained without vibrations are not stable to superposed vibrations (*A* conditions).

Obviously Ewing's statements quoted at the beginning of this paper are not universally applicable. Although his experimental methods, in which field change and tapping alternated, almost certainly precluded the observation of the neutral points, his statements are quite applicable to the *A* conditions whatever the intensity of the vibrations. They are, however, not applicable when applied to the *B* conditions, when the intensities of the vibrations are such that their effects have not reached a limiting value.

Molecular Theory.

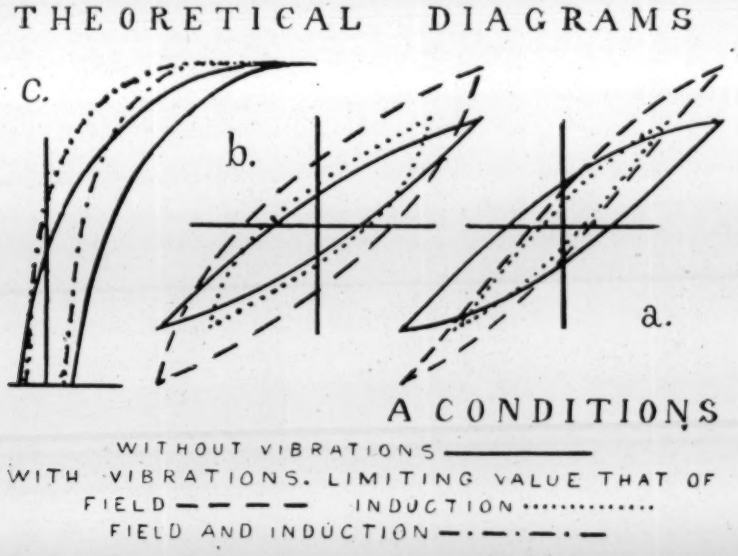
§ 182 of *Magnetic Induction in Iron* may be consulted. The general nature of the argument is shown by the following quotation:—"Any kind of disturbance that will give the molecular magnets intervals of freedom, or of diminished constraint, will tend to do away with hysteresis." This statement also appears completely applicable if the disturbances be superposed under the *A* conditions. Under the *B* conditions I prefer a deduction relative, not to hysteresis, but to the rate of magnetic change with field change, subject to any condition which the molecular theory may demand. However much B_v may exceed B in low fields, the ratio B_v/B must in high fields approximate to unity. Consequently, if the differential permeability in low fields be greater with than without vibrations, in high fields the reverse necessarily follows.

My deductions therefore are: (1) that if the cyclic amplitude be not unduly increased the differential permeability will be greater with than without permanently acting vibrations; (2) that the increase of differential permeability with vibrations may be associated either with increase or decrease of residual magnetisation, coercive force, or hysteresis loss, but that there is greater probability that those magnetic properties which depend upon hysteresis will be increased with vibrations for the same value

of field than for the same value of induction, and conversely, that there is greater probability that they will be decreased with vibrations for the same value of induction than for the same value of field.

The diagrams *a* and *b* illustrate the above deductions, and are self-explanatory. The continuous lines represent the normal loops without vibrations; the dash and dotted lines, the loops with permanently acting vibrations for the same values of field and induction at cyclic extremes respectively.

The experimental results show that the first deduction is fulfilled for the three magnetic metals examined, in the annealed and in the quenched condition alike. At every corresponding point of the loops the differential permeability is, so far as observed, greater with than without permanently acting vibrations. The second deduction is also supported by the results in so far as residual magnetisation, coercive force, and



hysteresis loss are invariably increased for the same value of low field at cyclic extremes, while coercive force and hysteresis loss are decreased, residual magnetisation only being increased in quenched nickel, for the same value of induction at cyclic extremes.

Further, the experimental results obtained do not exhaust all the possibilities of the effects of vibrations on magnetisation. For the same value of induction amplitude the descending and ascending arms of the loops, with and without vibrations, generally cross in the first and third quadrants respectively, as represented in diagram *a* (dotted curve), but in quenched nickel in the second and fourth quadrants respectively (see fig. XVI.), a position between the extreme positions represented by diagrams *a* and *b* (dotted curves).

The question therefore arises whether a condition of some magnetic metal or alloy could not be found, so that the arms of the loops would cross in the third and first quadrants respectively, as represented in diagram *b* (dotted curves). In this case not

only would residual magnetisation be increased with permanently acting vibrations (as in quenched nickel), but also coercive force and hysteresis loss, relative to the same value of induction. Such a result may be highly improbable, but its possibility does not appear to be excluded by these general theoretical considerations, and in the case of quenched nickel the experimental results are certainly converging in this direction.

Observe further that, however much the cyclic amplitudes be increased, the full and dotted line curves of diagrams *a* and *b* might still be used to illustrate the possibilities under deduction (2); but as the limiting value of magnetisation is approached, the vertices of both cycles would coincide, and the slope of the curves at high inductions would be less with than without vibrations, if the reverse held at low inductions.

Hence, when saturation values are departed from, the rate of magnetic change with field change would be less with than without permanently acting vibrations. Diagram *c* may be referred to, illustrating a position as regards the crossing points midway between the extremes shown in diagrams *a* and *b*.

Electric Oscillations.

The similarity between the effects of electric oscillations and mechanical vibrations was, as stated at the outset, anticipated. It has long been recognised that disturbances other than mechanical produce effects upon magnetisation essentially vibratory. A rise or a fall of temperature increases induction, decreases residual magnetisation.* Similarly, transverse magnetisation (which contributes nothing to the result) supplies the first molecular tap, which, if superposed at a cyclic extreme, produces increase of induction, or, if superposed when the field is withdrawn, a decrease of residual magnetisation. The experiments of Gerosa and Finzi and others of a similar nature are well known.

But in these latter cases the purely vibrational effects are materially altered by the direct magnetic effects of the subordinate unidirectional or alternating currents, and sooner or later the analogy becomes imperfect. Permeability is lowered in high fields, and direct hysteresis effects are unavoidable. On the other hand, as the direct magnetising action of high-frequency currents is very greatly reduced, it appeared reasonable to suppose that the vibrational effects due to high frequency would be increased, and consequently that the analogy between the magnetic effects of electric oscillations and mechanical vibrations would be more complete.

It became immediately apparent, as soon as this investigation was commenced, that the effects of mechanical vibrations upon magnetisation were essentially the same as those produced by electric oscillations in coils surrounding the iron previously dealt

* *Magnetic Induction in Iron*, 3rd ed., p. 181 (Wiedemann).

with (*Proc. R.S.E.*, vol. xxvi. p. 33). The experimental methods being the same in both cases facilitates comparison. Under both the *A* and *B* conditions the similarity extends to details.

It also appears evident that, had the experimental methods of the earlier investigations dealing with the effects of purely mechanical vibrations upon magnetisation been such as to elucidate the various phenomena involved under the *A* and *B* conditions, the results of later investigators (ASCOLI, ARNO, WALTER and EWING, GARIBALDI, MARCONI, MAURAIN, PIOLA, WILSON, and others) relative to the effects of electric oscillations upon magnetisation would have fallen more readily into line with each other * and with the effects of purely mechanical vibrations.

The effects, therefore, of electric oscillations upon magnetisation are essentially the same as those produced by mechanical vibrations.

CONCLUSION.

The experimental results given in this paper, summarised on pages 509 to 510, and discussed in their relation to magnetic hysteresis, molecular theory, and electric oscillations in the pages which follow, answer more or less completely the questions propounded when the effects of mechanical vibrations upon magnetisation have not reached a limiting value.

The experiments, however, were made, as has been stated, with wires subjected to a small load. A few of these have been repeated without load; wires of annealed iron and nickel were soldered to the gong, and supported in the glass tube by means of loose pads of cotton wool. The general relation of the curves to each other, as shown in figs. III. and V., were not found to be materially altered, although in the case of nickel the increase of the induction and residual magnetisation curves is considerable owing to the absence of load (see table, p. 494).

The results, therefore, in so far as common to the three magnetic metals examined in an annealed and quenched condition, may be concisely stated, without reference to load, as follows:—

(1) In all cases vibrations increase permeability (induction), but in high fields the ratio B_v/B approximates to unity.

(2) The effect of vibrations superposed at all stages of the normal loop (*A* conditions) is, generally speaking, to lessen those differences of magnetisation to which hysteresis *without vibrations has already given rise.*

(3) When change of field (cyclic or increasing from zero) is superposed upon permanently acting vibrations (*B* conditions), the differential permeability is increased in low fields, diminished in high fields. In sufficiently high fields vibrations must delay demagnetisation.

(4) The effects of electrical oscillations upon magnetisation supported by an

* "Notes on the Effect of Electric Oscillations on Magnetism," L. H. WALTER, *Electrician*, May 5, 1905.

independent field (which may be zero) are essentially the same as those produced by purely mechanical vibrations.

Within the limits stated under (1), (2), and (3), the effects of vibrations upon magnetisation exhibit striking differences between iron, steel, and nickel in the annealed and in the quenched conditions, which involve, more especially under (3) with cyclic fields, a complete study of the curves in each case (see summary of experimental results). The investigation cannot in any sense be regarded as exhaustive. Many additional inquiries present themselves, among which the following may be mentioned: —If the vibrations were such as to exhaust the possible increase of induction with increasing field, would hysteresis loss (for instance) be decreased instead of increased for the same value of low field at cyclic extremes? Under the same conditions, would residual magnetisation in quenched nickel be decreased instead of increased for the same value of low induction at cyclic extremes? The induction reached when vibrations are superposed (*A* conditions) is greater in nickel, less in iron and steel, than one-half the induction change on reversals when vibrations are superposed (*B* conditions). Does this fact throw any light on the relative inter-molecular controlling forces as they exist in these different metals?

In conclusion, this investigation was, as has already been pointed out, directly suggested by previous work on the effects of electric oscillations upon magnetisation, with which it is intimately associated. The results and suggestions obtained with purely mechanical vibrations undoubtedly facilitate further investigation in its theoretical and practical aspects (magnetic detectors) dealing with the primary objects of those researches for which the Royal Society of London placed at my disposal a Government grant, which I desire to acknowledge.

I also desire to express my indebtedness to Dr Peddie for advice kindly given at all times; and to Professor Macgregor for facilities to quench the wires, which I did not possess.

(Read December 17, 1906.)

In a paper* on "The Effect of Electric Oscillations on Iron in a Magnetic Field," read to the Physical Society on 22nd June 1906, Dr Eccles, in referring to my paper (*Proc. R.S.E.*, vol. xxvi. p. 33) on the same subject, states: "Russell applied to his iron the oscillations passing through a coil connected directly in series with a small induction coil. This last method appears to the writer to subject the iron to very violent treatment of a nature not easily described accurately; for how far the mere surgings of secondary current overwhelm in importance the genuine oscillations, it will be difficult to say."

I formally assumed that the effects upon magnetisation of oscillations produced as above described would not differ essentially from oscillations produced in wires by means of Hertz waves.

* *Phil. Mag.*, August 1906; *Electrician*, August 24, 1906.

On 14th and 15th July last I found this assumption to be absolutely correct. Oscillations (produced in the usual way by means of two small Leyden jars fed by induction coil, spark gap, and loosely coupled oscillation transformer) could either be passed directly through a long iron wire, ·041 cms. diameter, or through a coil of one layer surrounding it. In both cases the effects of these oscillations, when superposed under the *A* and also under the *B* conditions, were essentially the same as the effects of purely mechanical vibrations upon magnetisation. Any of the corresponding curves of figs. I. and II. (present paper) show the results obtained with sufficient accuracy.

I should like, however, to point out an essential particular in which Dr Eccles' experimental methods differ from my own. He states that "the effects of the spark are recorded as if the observations had been taken only on the ascending half of the hysteresis curve; the figures given being, in fact, the means of the measured effects at points symmetrical with regard to the origin on the ascending and descending branches." Consider, say, the 100 cycle of Table I. (*Phil. Mag.*, August 1906, p. 113). When the field is +100 the effect of the spark is +1·18. But this result has been obtained by taking the means at both cyclic extremes; hence, when the field is −100, the spark effect is −1·18. No readings are given in the third column when field is −75, but when it is reduced to −50 the effect of the spark is +0·27. The experiments, therefore, do not show how the transition from −1·18 at the negative cyclic extreme (field −100) to +0·27 when the field is reduced to −50 has taken place. This 100 cycle is typical of the other three cycles given.

Consequently, in the series of figures plotted from Table I. the curves measuring the effect of the spark on the ascending half of the hysteresis curve begin in the second and finish in the first quadrant, when in reality they ought to be represented by a continuous curve beginning in the third and finishing in the first quadrant.

Dr Eccles states that he found it possible "to get over and over again practically the same magnetometer deflection for every spark, provided the effect of previous oscillations was wiped out by taking the iron through *a cycle*." The fact that the observations could be repeated does not prove that the effect of previous oscillations had been wiped out. The cycle so obtained is not symmetrical about the origin, its want of symmetry being determined by the "set" or permanent deformation given to the magnetisation by the preceding oscillations. This is in accordance with the known facts of magnetisation. Moreover, I found, previous to determining my own experimental methods under the *A* conditions, that *repeated reversals of the cyclic field* were not sufficient to wipe out the effect of immediately preceding oscillations, and that to do so the magnetic metal must be demagnetised by decreasing reversals after each superposition of an electric oscillation or of a mechanical vibration.

One of the conclusions arrived at is as follows:—"It is evident, moreover, that the magnitude of the effect at any point is closely connected with the slope of the hysteresis curve." It is quite true that the maximum spark effect is closely connected with that point of the loop where the slope is greatest, but the occurrence of a neutral

point, now well established, after a cyclic extreme is departed from, and which may even occur close to the vertical axis, disposes of any connection between the value of dB/dH *at any point* and the magnitude of the spark effect. The spark effect, or the difference $B_v - B$ when vibrations are used, may be a simple function of dB/dH *at any point* when the B, H curve is determined by increments from zero; but this cannot be so during the cyclic process.

Dr Eccles' experimental method reproduces to a certain extent the working conditions of the first form of Marconi's magnetic detector of electric waves, and confirms the latter's experience that the magnitude of the spark effect is small as a cyclic extreme is departed from. But in neither case are oscillations superposed upon a hysteresis loop which has not already been modified by the effect of previous oscillations. In neither case are the *A* conditions fulfilled.

XVIII.—The Hydroids of the Scottish National Antarctic Expedition.

By James Ritchie, M.A., B.Sc., Fullerton Scholar, University of Aberdeen. *Communicated by* W. S. Bruce, F.R.S.E. (With Three Plates.)

(MS. received May 1, 1906. Read June 21, 1906. Issued separately March 16, 1907.)

The collection of Hydroids hereafter described was made in the years 1902–4 by the Scottish National Antarctic Expedition ship *Scotia*, during her cruises in Antarctic and sub-Antarctic seas.

For the opportunity of examining the specimens I am indebted to Mr W. S. Bruce, the energetic leader of the expedition; and I also wish to thank Professor J. Arthur Thomson for much assistance and advice in the course of my work.

The collection, as here described, contains 41 specimens, of which 33 are referable to 27 known species distributed among 15 genera, some of them being new varieties; while the remainder have required the establishment of 7 new species and 1 new genus. One specimen remains specifically undetermined. Thus there are in all 18 different genera, represented by 35 different species.

Before dealing with the detailed systematic aspect of these forms, a few general notes may be inserted:—

(1) The habitat of the forms shows considerable diversity. Sixteen of the specimens were associated with Alcyonarians, being found along with, or growing upon, those forwarded to Professor Thomson for identification; eight occurred upon larger Hydroids; while two were creeping upon seaweed fronds. Sponges formed the foundation upon which several of the remaining colonies were erected.

(2) With the specimens were associated many types of life. Frequent diatoms and foraminifera lay within the hydrothecæ or upon the stems; various sponges rested upon or surrounded some of the branches; and there were also numerous climbing or encrusting polyzoa, a few cirripede galls, and occasional pycnogonids.

(3) Of new forms described the most interesting is one of those rare types, apart from the Plumularians, in which distinct nematophore structures have been found (Allman, 1883, p. 6; Quelch, 1885, p. 4), and for it we have formed a new genus, which we have named *Brucella* in honour of Mr Bruce. The beautiful, highly specialised coppinia-gonosome of this type indicates close affinities with the family Lafoëidæ in which it has been placed.

(4) Another new form, belonging to the genus Staurotheca, is also worthy of mention as showing a development of the decussate arrangement of hydrothecæ, which necessitates a slight modification in the generic characters as originally described by ALLMAN (1888, p. 75).

(5) The occurrence among the specimens of the coppinia-gonosome of *Grammaria*, which has only within the last few months been described by HARTLAUB (1905, p. 597), is of interest, since the peculiar structure of this gonosome aggregate necessitates the transference of the genus from the neighbourhood of the Sertulariidæ, where it had been placed by ALLMAN in 1888, to close proximity with the far-removed Lafoëidæ.

(6) Throughout the genus *Halecium*, here represented by five species, the occurrence of minute, translucent points round the rim of the hydrotheca has been noted (Pl. II. fig. 5). These points, whose use ALLMAN did not happen to observe, are small, dome-shaped thickenings on the inside of the perisarc, placed in a ring just above the base of the hydrotheca, and to these are attached short strands from a disc-like portion at the base of the polyp, which is thus moored to the walls of its insignificant hydrotheca. Such refringent puncta are not confined to the Haleciidæ, for similar structures in the same position—just above the floor of the hydrotheca—were observed in the hydrothecæ of *Obelia geniculata*.

(7) The *Scotia* collection contributes also to our knowledge of the geographical distribution of Hydroids. Thus to the already wide distribution, Arctic to Antarctic, of such forms as *Lafoëa gracillima* (Spitsbergen, Norwegian coasts, British coasts, Magellan Straits, etc.) or *Obelia geniculata* (Norwegian coasts, British coasts, French coasts, Kerguelen, etc.), still another locality is added, while several new records have been made of the occurrence of less common forms.

(8) As a remarkable case of associated distribution we may refer to *Silicularia hemisphærica*, a simple Campanularian form, which has been recorded from three different localities, namely, Falkland Islands (ALLMAN, 1888), Navarin Island, Tierra del Fuego (HARTLAUB, 1905), and Gough Island (*Scotia*), and in each case it was found in close association with *Obelia geniculata*.

In classifying the specimens according to their geographical occurrence, the regions mapped out by ORTMANN (1896) and made use of by Professor HARTLAUB (1904) have been adopted. Taking these as our standard, we find that ten of our specimens fall into the Antarctic Pelagic Region, all belonging to the Southern Subregion, while twenty-nine, including all the new forms, have been found in the Antarctic Littoral Region. The remaining two were obtained at St Helena.

Before dealing with the systematic aspect of the collection, I should like to express my special indebtedness to Professor HARTLAUB'S "Hydroiden der magalhaensischen Region und chilenischen Küste" in the *Zoologische Jahrbücher* (1905), and to Professor NUTTING'S excellent monographs on the American Hydroids (1900 and 1904).

Arranging the *Scotia* specimens according to the localities in which they were obtained, we get the following list:—

ANTARCTIC PELAGIC REGION.

(*a*) Antarctic circumpolar subregion.

Nil.

(*b*) Southern circumpolar subregion.

BURDWOOD BANK, 54° 25′ S., 57° 32′ W. 56 fms. 1st December 1903.

* *Hebella striata*, Allm.
* *Calycella syringa*, Linn.
Lafoëa antarctica, Hart.
* „ *gracillima* (Alder).
* *Grammaria magellanica*, Allm.
* *Halecium beanii*, Johns.
* *Synthecium robustum*, Nutt.
* *Sertularella filiformis*, var. *reticulata*, n. var.
* „ *tenella*, Alder.
* „ *tricuspidata*, Alder.

ANTARCTIC LITTORAL REGION.

FALKLAND ISLANDS.

(*a*) Port Stanley. 8th January 1903.

* *Campanularia angulata*, Hinks.
„ *tincta*, Hinks.
Sertularella contorta, Kirch.
Plumularia magellanica, Hart.

(*b*) Cape Pembroke. January 1903 to January 1904.

Sertularella contorta, Kirch.

SOUTH ORKNEY ISLANDS.

(*a*) MacDougall Bay. November 1903.

Obelia longissima, Pall.

(*b*) Scotia Bay. 25th March and 6th December 1903.

Campanularia, sp.
Obelia longissima, Pall.
* *Halecium interpolatum*, n. sp.
* *Staurotheca reticulata*, n. sp.
* *Sertularella rectitheca*, n. sp.

STATION 411, off Coat's Land, 74° 1′ S., 22° 0′ W. 12th March 1903.

Hebella striata, var. *plana*.
Halecium robustum, Allm.

GOUGH ISLAND. 22nd April 1904.

Silicularia hemispherica, Allm.
Obelia geniculata, Linn.
* *Brucella armata*, nov. gen. et sp.
Halecium tenellum, Hinks.
Sertularella gayi, Lamx.

CAPE COLONY.

(*a*) Cape Town Docks. May 1904.

Plumularia echinulata, Lamk.
„ *pinnata*, Linn.

* Indicates a new record for the Geographical Region.

Cape Colony—*cont.*

(*b*) 8 miles N. of Dassen Island. 18th May 1904.

Sertularella filiformis, var. *reticulata*, n. var.

(*c*) Saldanha Bay. 21st May 1904.

* *Podocoryne carnea*, Sars.
* *Halecium halecinum*, Linn.
Thujaria pectinata, Allm.
Sertularella arborea, Kirch.
* *Antennularia hartlaubi*, n. sp.
* *Antennopsis scotiæ*, n. sp.
* *Plumularia unilateralis*, n. sp.
Aglaophenia dichotoma (Johns.).

St Helena.

Halecium robustum, Allm.
„ *tenellum*, Hinks.

The systematic grouping of the species represented in the *Scotia* collection is as follows:—

I. GYMNOBLASTEA.

Family Podocorynidæ.

Podocoryne carnea, Sars, 1846.

II. CALYPTOBLASTEA.

Family Haleciidæ.

Halecium beanii, Johns., 1847.
„ *halecinum*, Linn., 1758.
„ *robustum*, Allm., 1888.
Halecium tenellum, Hinks, 1861.
„ *interpolatum*, n. sp.

Family Campanulariidæ.

Campanularia angulata, Hinks, 1861.
„ *tincta*, Hinks, 1861.
„ sp.
Obelia geniculata, Linn., 1758.
„ *longissima*, Pall., 1766.
Silicularia hemisphærica, Allm., 1888.
Hebella striata, Allm., 1888.
„ *striata*, var. *plana*, n. var.
Calycella syringa, Linn.

Family Lafoëidæ.

Lafoëa antarctica, Hartlaub, 1905.
„ *gracillima* (Alder, 1857).
Grammaria magellanica, Allm., 1888.
Brucella armata, n. gen. et sp.

Family Sertulariidæ.

Sertularella arborea, Kirch., 1884.
„ *contorta*, Kirch., 1884.
„ *filiformis*, var. *reticulata*, n. var.
„ *gayi*, Lamx., 1821.
„ *tenella* (Alder, 1857).
Sertularella tricuspidata (Alder, 1856).
„ *rectitheca*, n. sp.
Thujaria pectinata, Allm., 1888.
Synthecium robustum, Nutt., 1904.
Staurotheca reticulata, n. sp.

Family PLUMULARIIDÆ.

Aglaophenia dichotoma (Johns.).
Plumularia echinulata (Lamk., 1836).
„ *magellanica*, Hart., 1905.
„ *pinnata*, Linn.
Plumularia unilateralis, n. sp.
Antennularia hartlaubi, n. sp.
Antennopsis scotiæ, n. sp.

I. GYMNOBLASTEA.

Family PODOCORYNIDÆ.

Podocoryne carnea, Sars, 1846.

Encrusting three Gasteropod shells from one locality there occur gymnoblastic colonies which cannot be separated from the above species. The nutritive hydranths bear from 8 to 15 tentacles, 12 being most common, while the gonophore-bearing individuals possess only 5 or 6. All the hydranths are in a contracted state, some of the larger measuring about 0·8 mm. in height. Short chitinous spines stud the investing crust at irregular intervals.

The gonophores are borne in threes or fours beneath the tentacles. The medusoid has 8 tentacles, 4 larger and 4 smaller.

Locality, etc.—On empty shells of *Nassa crepidula* from Saldanha Bay, Cape Colony. Trawl. 19th May 1904.

II. CALYPTOBLASTEA.

Family HALECIIDÆ.

Haleciun beanii, Johnstone, 1847.

Two fragments occur, one 4, the other 7 cm. high. The characters of the species are well shown in the specimens; the polysiphonic stems and branches which distally become monosiphonic; the pinnate arrangement of the branches; the extreme delicacy of the ramuli, especially in the distal regions; the frequent tiers of hydrothecæ and the peculiar female slipper-shaped gonothecæ, with their openings placed medianly instead of at the extremity. In the present specimens, as in ALLMAN'S (1888), only slipper-shaped gonothecæ occur. We note, however, that while the hydrothecæ are in some cases set on a "*short basal offset* from the distal end of each indernode" (ALLMAN, 1888, p. 12), in the majority of cases the primary hydrotheca arises directly from and lies almost against the distal end of the internode, as figured by HARTLAUB (1905, p. 606, fig. B^3, *a* and *b*). From within these primary basal hydrothecæ arise the tiers which are so common in the species.

Locality, etc.—Fathoms, 56. Date, 1st December 1903. Burdwood Bank.

Halecium halecinum, Linn., 1758.

A thick clump of stout fascicled stems and branches from the entrance to Saldanha Bay. The stems and branches are truncated at an almost uniform height, are of a dark brown colour, and bear small, hydrotheca-bearing shoots of a pale brown, and evidently of younger age. The general appearance suggests that some agency having damaged the old-established branches, the colonies have made an effort to survive by sending out many small, much-branched shoots from the older and unharmed portions of the stem.

The architecture is similar to that described by HINKS. The hydrothecæ are alternate, one towards the distal end of each internode. They are generally sessile, as described and figured by BILLARD (1904, p. 161) for young branches, and frequently they contain the base of a tier of one or two secondary cups. Rarely in place of such a tier there arises a blind regenerative stolon, the true branches arising just below the hydrothecæ. Thus it comes about that a tier of hydrothecæ frequently appears in the angle between a branch and its offshoot. Small refringent points are present round the edge of the hydrotheca as in the other species of the genus (*vide* p. 525).

Gonosome.—The gonangia, of which only male are present, occur in densely packed rows. They agree with HINKS's description and figure, being slenderly ovate and narrowing proximally into a short stalk with about two rings.

Locality, etc.—Entrance to Saldanha Bay, Cape Colony, in 25 fathoms. Date, 21st May 1904.

Halecium robustum, Allman, 1888.

A fragment of a strongly fascicled, upright, much-branched colony 5 cm. in height. The branches lie roughly in one plane and are often bent at sharp angles, the older rising irregularly from the stem, while the younger are approximately alternate, and arise from the side of the proximal segment of the hydrotheca. The internodes, which are long, but whose length varies from 0·6 to 1·5 mm., are separated by slanting nodes and bear at their distal ends alternate hydrothecæ 0·2 mm. in diameter from margin to margin, adnate at one side to the internode, with an insignificant, non-everted limbus, and rarely with a tier of one or two secondary hydrothecæ. The proximal ends of the internodes are marked by slight annulations. Around the inside of the limbus are situated small, light-refracting prominences, to which, as in the other members of the genus, are attached strands keeping in place a fleshy disc at the base of the hydranth which cuts off the perisarcal cavity from the exterior. The hydranths are large and have a great number of tentacles.

Gonosome.—Not present.

Localities, etc.—(*a*) Station 411, off Coat's Land. Lat., 74° 1′ S; long., 22° 0′ W. Depth, 161 fathoms. Surface temperature, 28°·9. Date, 12th March 1904. (*b*) St Helena.

The specimens differ from that figured by ALLMAN (1888) in that the branches

frequently have at their bases at least one athecate internode connecting the stem process with the hydrophore-bearing portions of the branch. The present specimens are also frequently annulated, while ALLMAN's figures indicate that the original was smooth.

Halecium tenellum, Hinks, 1861. (Pl. II. fig. 4.)

Several specimens of an extremely delicate and graceful hydroid colony, growing in bunches on the exposed axis of an Alcyonarian, are referable to this species. As HINKS's description appears to be rather vague, I give a detailed description of the specimens. The colonies are short, generally about 15 mm. in length, with unfascicled stems and irregular branches, which arise from the distal ends of the internodes, and in some cases, at least, from the base of a hydrophore. The branches lie for the most part in one plane.

The stem is thin, having near its base a diameter of a little over 0·1 mm., and, like the branches, it is divided into long slender internodes whose length varies between 0·8 and 0·9 mm. The internodes are separated by slanting nodes, between which the stem zigzags, and on each side of which are annular constrictions. The hydrothecæ, which are alternate and lie in one plane, are borne on short processes at the distal ends of the internodes. They are cylindrical, trumpet-shaped, with a large, beautifully everted limbus, and are usually prolonged by several similar segments (from two to five in number), at the bases of which, on a level with the margin of the next lower limbus, arise well-marked annulations. The diameter of a limbus from margin to margin is 0·15 mm.

The fleshy parts are in good condition, and the following points were observed:— The hydranths are large and not wholly retractile, measuring, from mouth of hydrotheca to summit of hypostome, when extended, 0·3 mm. Just above the neck there is a well-defined bulge, and above this again a disc, from the margin of which arise the tentacles, about sixteen in number, enclosing the conical hypostome. Across the interior of the hydrotheca, at the level of the base of the everted limbus, stretches a flattened fleshy disc supported by a perisarcal septum through which, by a small aperture, the coenosarc passes. The disc is moored in its place by numerous delicate strands attached to the perisarc at rather irregular intervals. At the points of attachment there arise from the limbus small, dome-shaped prominences, which, refracting the light, appear as minute, clear dots—the "refringent puncta" of the Challenger Report. The prominences are rather irregularly arranged just above the level of the septum, on which the coenosarcal disc lies, and vary in number from about sixteen to twenty on each limbus.

Gonosome.—The gonangia are ovate, broad in the proximal region, obtusely pointed in the distal. They are supported on short stalks which arise from the sides of the hydrothecæ, and always from the lowest segment in any hydrotheca-tier. They are 0·9 mm. in length by 0·45 mm. in maximum diameter.

Localities, etc.—(*a*) Growing on the axis of an Alcyonarian (*Thouarella*), and dredged off Gough Island, lat. 40° 20′ S, long. 9° 56′ W., at a depth of 100 fathoms. Date, 22nd April 1904. (*b*) St Helena.

Halecium interpolatum, n. sp. (Pl. I. fig. 3; Pl. II. fig. 3.)

A number of colonies, the largest about 4 cm. high, have been found in a shore-pool. The colony is fascicled for the most part, but becomes monosiphonic distally. In the older colonies the lower portion of the stem, which is less than 1 mm. in diameter, is usually destitute of important branches, while the upper portion bears long flexuous branches, often 15 mm. in length, which leave the stem at acute angles and in different planes. This structure gives the colonies the appearance of a miniature tree. The branches arise either singly from the basal segment of a hydrotheca or directly from the hydrocaulus, in diverging pairs, one being at a slightly higher level than the other.

The stem and branches are divided into slender internodes of very different lengths, varying from over 1 mm. to 0·4 mm., and marked at both ends by an annulation. The hydrothecæ are alternate, and are borne at the distal ends of the internodes, two thecate internodes being almost invariably separated by one or more athecate internodes. Very frequently a short, annulated, hydrotheca-crowned branch arises from the basal segment of a primary hydrotheca. The hydrothecæ are usually simple, consisting of a strongly annulated peduncle about 1 mm. long, surmounted by a well-everted limbus measuring 0·2 mm. from margin to margin. Occasionally a second limbus arises on a short stalk within the first. Around the limbus occurs the row of refringent prominences found throughout the genus, and here, as in the other cases which have been examined, they serve as attachment points for strands supporting a disc at the base of the polyp.

Gonosome.—Not present.

Locality, etc.—Off rocks in shore-pool. Temperature, 30°–32°. Scotia Bay, South Orkneys. 6th December 1903.

One of the branches ended in peculiar, stolon-like outgrowths, as is shown in fig. 3, Pl. II. The specimens, which have probably been cast by some storm into the shore-pool in which they were found, are in poor condition, being almost wholly overgrown by polyzoa. The specific name is intended to suggest the presence of the characteristic athecate intermediate internodes.

Family Campanulariidæ.

Campanularia angulata, Hinks, 1861.

Several specimens about 1 cm. high were found creeping on an alga. The specimens agree with Hinks's description:—slightly branched stems ringed above the origin of the pedicels; strongly ringed pedicels, usually with nine rings, sometimes with only about

five, and tapering somewhat towards their distal ends; hydrothecæ campanulate, even-rimmed, usually on long pedicels. In the present specimens there are present none of the tendril-like stolons mentioned by most writers, but this is not surprising, since in most cases the distal end of the colony is awanting.

Gonosome.—Not present.

Locality, etc.—Port Stanley, Falkland Islands; 64 fathoms. 3rd February 1904.

Campanularia tincta, Hinks, 1861.

This species is represented from one locality, that from which HARTLAUB (1905) has described his specimens. The *Scotia* specimens, while apparently belonging to this species, show a considerable resemblance to *C. cylindrica*, Allm. (1876, p. 114), from which they differ in their diminutive size and in the absence of ringing at the base of the peduncle. The present specimens, which are from 1·5 to 2 mm. high, have a corrugated peduncle averaging some 0·9 mm. in height and surmounted by a ball-like segment which bears the hydrotheca. The hydrothecæ are about 0·7 mm. long by 0·3 mm. in diameter, almost cylindrical, and narrow sharply at the base. The margin is divided into twelve blunt teeth and is frequently marked by a regeneration line. The gonosome is awanting.

Locality, etc.—Creeping on weathered hydroid stems, Port Stanley, Falkland Islands. 3rd February 1904.

Campanularia, sp. (Pl. I. fig. 2.)

Lack of material forbids the assigning of a specific name to this form. Delicate simple stems about 3 mm. high and 0·05 mm. in diameter arise at irregular intervals from a creeping tubular stolon. The hydrothecæ are deep, campanulate, 0·8 mm. in length by 0·5 mm. in greatest diameter, with their cavity cut off from that of the stem by a distinct partition. Their margin is divided into twelve or fourteen teeth, a delicate line sometimes following the curves of the teeth just within the edge. The hydrothecæ, which are marked by delicate, longitudinal lines passing from the notches between the teeth to the base, are borne upon peduncles about 3 mm. long with several rings at the top. These rings seem to be fairly constant, two deep constrictions giving rise to two ball-like divisions which are followed by an indistinctly ringed portion of the peduncle, cut off from the remainder, which is smooth, by another deep constriction.

Gonosome.—Not present.

Locality, etc.—Growing on *Staurotheca reticulata*, Scotia Bay, South Orkneys. Depth, 65 fathoms. Date, 25th March 1903.

The specimen approaches *C. Hinksii* (Alder, 1857), but the typical campanulate form of the hydrothecæ, the blunt teeth, and the peculiar markings on the peduncle, distinguish it from the parallel-sided hydrothecæ, the square-topped teeth, and the

characteristic ringing of *C. Hinksii*, where the first annulation is included in the base of the hydrotheca. From *C. cylindrica*, Allm., and *C. tincta*, Allm., it is also distinguished by its campanulate form and its peduncle characters.

Obelia geniculata, Linnæus, 1758.

Several specimens of this well-marked species were obtained growing on the fronds of a large seaweed—*Macrocystis pyrifera.*

The hydrotheca-bearing shoots, which are generally simple and average only 12 mm. in height, arise from a creeping stolon which ramifies over the surface of the seaweed frond. The trophosome agrees with the description in HINKS's *British Hydroid Zoophytes*, but here the annulations on the peduncle are rather more variable—two or three as well as a larger number being common. Within the hydrotheca, a short distance from the base, a perisarcal ridge is well marked, supporting the flattened basal portion of the polyp. Just above this bracket there occurs an irregular ring of minute refringent spots—small prominences on the inner side of the hydrotheca wall—to which the basal disc of the polyp is attached. These prominences resemble and serve the same purpose as those found throughout the genus *Halecium* (*vide* p. 525). The polyps are well preserved, and show well the large, trumpet-shaped proboscis.

Gonosome.—Absent.

Locality, etc.—Growing on the fronds of *Macrocystis pyrifera*, Gough Island. Lat., 40° 20′ S.; long., 9° 56′ W. Date, 22nd April 1904.

Obelia longissima, Pallas, 1766.

A large number of weather-beaten colonies were found in the South Orkneys. The specimens are about 8 cm. high and agree closely with HINKS's description and figures. The hydrothecæ are mostly awanting; those which remain are fragile and much crushed, and probably as a consequence I was unable to detect the blunt teeth which mark the rim. The pedicels, which taper towards the top, are usually altogether ringed, but sometimes only in the proximal and distal regions, the median portion being smooth. A pedicel was frequently noted springing from the axil between branch and branchlet, as mentioned by HINKS (1868).

Subsequent specimens, residue from the seaweed collections, were in better condition.

Gonosome.—Wanting.

Localities, etc.—(*a*) Macdougall Bay, South Orkneys. November 1903. (*b*) Off rocks in shore-pool, Scotia Bay, South Orkneys. Temperature, 30° to 32°. Date, 6th December 1903.

The specimens from both localities appear to have been exposed to weathering for some time. Those from (*b*) especially show traces of rough usage, the branches being

broken off not far from their origin, while the greater number of the stems are covered with polyzoon growths.

Silicularia hemispherica = *Hypanthea hemispherica*, Allman, 1888.

The only representative of this genus in the *Scotia* collection occurs on the frond of *Macrocystis pyrifera*, from Gough Island. The specimens bear out HARTLAUB'S opinion that the length of the peduncle, varying as it does to a considerable extent, is not a safe specific character, for here various peduncles measure 6, 5, 4, 3, 1 mm. In so simple a genus distinctive specific characters are not easily obtained, but the following point to identity with *S. hemispherica*:—Hydrocaulus, creeping, branched, bearing at varying distances pedunculate hydrothecæ and gonangia which usually alternate with one another. The peduncles are exceedingly variable in length, rather less in diameter than the hydrocaulus, with a distal swelling, succeeded by a globular segment, and this in turn by the hydrotheca. The hydrotheca is conical, almost as broad as long, about 0·7 mm. high by 0·5 mm. in greatest diameter, with a markedly oblique margin.

The gonangia are 2 mm. long by 0·6 mm. in diameter, narrowing slightly towards the opening, and considerably towards the base, where they are supported by a distinct peduncle. They are never grouped on the hydrocaulus.

Locality, etc.—Creeping over the fronds of *Macrocystis pyrifera*, Gough Island. Lat., 40° 20′ S.; long., 9° 56′ W. Date, 22nd April 1904.

Hebella striata, Allman, 1888. (Pl. I. fig. 7.)

Several specimens of the beautiful species described by ALLMAN in the Challenger Reports occur creeping on the stems and branches of various larger Hydroids. The hydrothecæ are large, almost 1 mm. in length by from 0·22 to 0·25 mm. in diameter, cylindrical, borne on short, untwisted peduncles varying in length from 0·25 to 0·4 mm. In some the characteristic ringing exists only on the lower half of the wall, part towards the margin being smooth. The hydranths are in all cases contracted, and in this state occupy only the lower half of the hydrotheca. They are in good condition, and show in their contracted state a bulging body, separated from a fleshy disc at the base of the hydrotheca by a marked constriction, and surmounted by another constriction from above which arises a whorl of tentacles. Within the tentacles there arises a conical hypostome.

Gonosome.—Not present.

Locality, etc.—Creeping on the stems and branches of *Lafoëa gracillima*, *Grammaria magellanica*, *Sertularella filiformis*, Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W.; 56 fathoms. 1st December 1903.

Hebella striata, var. *plana*, n. var. (Pl. I. Fig. 8.)

A colony creeping upon *Halecium robustum*, whose habit and general appearance resemble those of *H. striata*. The hydrothecæ, however, are rather larger, 1·3 to 1·4 mm. in length by 0·28 mm. in diameter, and show no hint of the annular thickenings of perisarc which form the characteristic striations. Marginal reduplications were noted in some cases, while a solitary peduncle was marked by a thickened ring near its base.

Gonosome.—Not present.

Locality, etc.—Creeping on the stems and branches of *Halecium robustum*, from Station 411. Lat., 74° 1′ S.; long., 22° 0′ W. Depth, 161 fathoms. Surface temperature, 28°·9. 12th March 1904.

In none of the true *H. striata* colonies did there occur hydrothecæ with more than about a third of their surface smooth, the remainder of course being striated, and even these were exceptional. Hence an entirely smooth hydrotheca seems worthy of being considered a distinct variety.

Calycella syringa, Linnæus, 1758.

Arising from a tubular, creeping stolon are several minute, extremely delicate, almost campanulate hydrothecæ whose cavities are separated from those of their peduncles by thin partitions. They are operculated, and are borne on peduncles of variable length which are always marked by many strong annulations.

The absence of gonosomes and the unsatisfactory state of the hydranths render accurate identification impossible, but the trophosome agrees with Hinks's (1868) description of *C. syringa*, except in that the "horn-colour" is lacking.

Measurements.—Hydrotheca: length, including operculum, 0·2 mm.; diameter, 0·1 mm. Peduncle: length, 0·2 mm.

Locality.—Burdwood Bank. Lat., 54° 25′ S.; long., 57° 31′ W. 56 Fathoms. 1st December 1903.

Family Lafoëidæ.

Lafoëa antarctica, Hartlaub, 1904.

The above species occurs on the stems and branches of *Sertularella filiformis*. It agrees in all respects with the description given by Hartlaub. The large number of the regeneration rings on the hydrothecæ is especially noticeable—six being not unusual. The length of the hydrothecæ, from where they leave the stem at right angles, to the margin, averages 5 or 6 mm., while the diameter is about 1·25 mm.

Locality, etc.—Creeping on the branches of *Sertularella filiformis*, from Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W. Fathoms, 56. Date, 1st December 1903.

Previous Locality.—70° 23′ S.; 82° 47′ W.

Lafoëa gracillima (Alder, 1857).

Several specimens referable to this species occur growing on the horny axis of an Alcyonarian. They agree in all but size with the specimens described by BONNEVIE (1899), the largest reaching a height of only 3 cm., while the general size lies between 2 and 3 cm. The colonies are erect and branched, without any distinct stem, the greater number of the branches lying in one plane and showing a tendency to be more strongly developed on one side. Except towards the tip, where they are monosiphonic, the branches are fascicled. The hydrothecæ are long narrow cylinders 0·5 mm. in length by 0·1 mm. in greatest diameter, sometimes with reduplication rings round their margins. They arise irregularly from all sides of the hydrocaulus, and are borne on loosely twisted peduncles bearing two turns of a spiral.

Gonosome.—Not observed.

Locality, etc.—Growing on the axis of an Alcyonarian (Gorgonid) in 56 fathoms. Date, 1st December 1903. Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W.

Grammaria magellanica, Allman, 1888. (Pl. I. figs. 4, 4A.)

Three colonies varying in height from 6 cm. to 16 cm., and in breadth from 7 cm. to 12 cm. The stem is fascicled and thick, reaching just above the base a diameter of about 3 mm. and gradually tapering towards its summit. In two of the specimens it divides about 1 cm. above the base into two or three equally developed, strong branches, and these, together with the stem itself in the other specimen, bear along their length usually alternate ramuli, which sometimes reach a length of 14 cm. These primary ramuli bear secondary, and these again may bear tertiary, pinnæ-bearing branches. On all the branches, and on the main stem between the branches, there are alternately-set pinnæ usually between 10 mm. and 15 mm. in length, which become greatly constricted at their point of origin. All the branches and pinnæ lie in one plane, and in the largest specimen anastomosis occasionally occurs between them. The hydrothecæ are placed in successive planes, in whorls of three, which alternate with one another so that there are six longitudinal rows on the colony. They are cylindrical, and have a circular opening with an even, non-everted margin.

Gonosome.—The gonangia are grouped together into irregular bunches which surround portions of the stem and the bases of such branches as arise from these portions. In the largest of the three colonies two bunches of clustered gonangia were found, the larger 30 mm. long by 3 mm. in diameter, the smaller 20 mm. long by about 2 mm. in diameter, while on another colony a still smaller cluster occurred. These coppiniæ are elongated clusters of compressed gonangia growing closely around the stem for a considerable distance, and bristling with minute projecting tubes which are without the irregular bendings figured by HARTLAUB (1905). Under the microscope the cluster resolves itself into a large number of hexagonal cells, closely resembling honey-

comb—the compressed gonangia—from among which spring many short, uncoiled tubes 0·4 to 0·5 mm. in length.

Locality.—Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W. Depth, 56 fathoms. 1st December 1903.

As the species was named by ALLMAN from small fragments, and as subsequent specimens collected by PAESSLER in 1893 off Australia were also fragmental, I have thought it necessary to give a rather full account of the structure of the colony to supplement the original description. Since HARTLAUB figures only longitudinal and transverse sections of the coppinia (HARTLAUB, 1905, p. 597), representations of the general appearance and magnified surface view have been here included.

Brucella, nov. gen.

We have named this genus after Mr BRUCE, the leader of the expedition.

Generic Characters. Trophosome.—Stem and branches fascicled for the most part, becoming monosiphonic distally; consisting of an axial tube predominantly hydrotheca-bearing, surrounded by peripheral tubes which may occasionally bear hydrothecæ and nematophores. Hydrothecæ tubular, fastened by their bases to a process of the hydrocaulus, their cavity being distinctly differentiated from that of the peduncle. Each hydrotheca is accompanied by a basal pair of nematophores.

Gonosome.—A coppinia, that is, a bunch of clustered gonangia surrounding the hydrocaulus, from which a number of delicate tubes arise.

The genus shows affinities with *Perisiphonia*, Allman (ALLMAN, 1888, p. 43) and *Zygophylax*, Quelch (QUELCH, 1885, p. 4). From the former it can be distinguished by its manner of fascicling, its arrangement of nematophores, and, perhaps not so certainly, by the shape of the hydrothecæ. The chief points of difference are summarised in the following table:—

Perisiphonia.	*Brucella.*
Axial tube completely enveloped.	Axial tube not completely enveloped.
No hydrothecæ on peripheral tubes.	Scattered hydrothecæ on peripheral tubes.
Nematophores frequent and regular on peripheral tubes.	Nematophores scattered and irregular on the peripheral tubes.
Nematophores present or absent from axial tube.	Two nematophores at base of each hydrotheca on axial tube.
Hydrothecæ flask-shaped.	Hydrothecæ tubular.

From *Zygophylax*, to which it is closely allied, it can readily be distinguished by the distinct differentiation of the hydrotheca cavity from that of the peduncle, and by the scattered nematophores on the peripheral tubes.

A portion of a specimen when softened in caustic potash and dissected, showed a central, predominantly hydrotheca-bearing tube, surrounded by peripheral tubes, which were sometimes simple, sometimes branched, and sometimes bearing scattered hydrothecæ and nematophores. The structure of the fasciculation seemed to resemble that

in *Sertularella gayi* as described by NUTTING, 1904, p. 6, although I found difficulty in tracing the peripheral tubes to their origin. The peripheral tubes certainly never become hydrotheca-bearing to the same extent as in *Sertularella gayi*.

The characters of the trophosome, and especially of the gonosome, appear to indicate close relationship with the Lafoëidæ, in which family the genus has accordingly been placed.

Brucella armata, n. sp. (Pl. II. figs. 2A, 2B, 2C.)

Several specimens have been obtained of a colony for which the above new genus has been formed. The colonies, which are erect and much branched, with both stem and branches thickly fascicled, reach in some cases a height of 6 cm. by a similar breadth. Owing to this great breadth, as compared with height, and to the fact that the many branches lie in one plane, the colony assumes a somewhat flabellate appearance. It is of a pale brown colour, becoming lighter towards the tips of the branches. Except distally, where for a short distance they become monosiphonic, the stem and branches are fascicled, consisting of an axial tube, predominantly hydrotheca-bearing, surrounded by peripheral tubes which may bear occasional hydrothecæ and scattered nematophores. The main *branches*, which may reach a length of 5 cm., leave the stem at irregular intervals, although frequently there is an approximation to alternate arrangement, while those borne by the main branches are regularly pinnate and alternate and are rarely branched. All the branches lie in one plane, and arise from below a hydrotheca, which then lies in the axil of the branch. The cavity of the axial tube is continuous; the tube is not divided into internodes, but bears alternately at regular intervals small processes to which the hydrothecæ are attached. The *hydrothecæ* are biserial, alternate, tubular, with an entire margin which is not parallel to the axis of the hydrocaulus. Their upper side is curved, while the lower is almost straight, and their cavity is cut off from that of the rest of the colony by a strong septal ridge at their junction with the hydrocaulus process. Above this occur one or two delicate, membranaceous intrathecal septa apparently stretching across the cavity of the hydrotheca, while near the edge there are usually two or three lines indicating the presence of marginal reduplications. The length of the hydrothecæ from basal septum to margin is between 0·3 and 0·35 mm., while the greatest diameter is from 0·13 to 0·15 mm. Towards the base they become constricted and rest upon a short process of the hydrocaulus, from each side of which springs a nematophore. The *nematophores* are small, only 0·1 mm. long by 0·04 mm. in diameter, and resemble those found in some of the Eleutheroplean Plumularians, consisting of two joints, the proximal, a narrow tube, the distal, a wider tube opening out slightly towards the margin, round which there is frequently a reduplication line. This whole two-jointed structure is sometimes loosely incased in an unjointed tube. Scattered nematophores of similar structure occur frequently but irregularly on the peripheral tubes. The form of the hydranth could not be distinguished.

Gonosome.—On one specimen were found two clusters of gonangia, the larger measuring 5 mm. in length by 3 mm. in diameter, the smaller 5 mm. by 2 mm. The clusters or coppiniæ form elongated ovals surrounding the stem and the bases of branches in the neighbourhood. They consist of numerous gonangia so closely packed that the sides become compressed and the whole assumes a honeycomb-like structure consisting of a dense mass of polygonal, usually hexagonal, cells, the majority of which communicate with the exterior by an exceedingly short tube. Issuing from this gonangial cluster are frequent tubes of various shapes; a few, especially at the ends, are merely two-jointed tubes like cauline nematophores with their basal joint elongated, while the majority consist of a longer tube 1 mm. in length bearing alternate biserial nematophore-like bodies identical in structure with the nematophores on the trophosome.

Locality, etc.—Growing on the axis of an Alcyonarian (Gorgonid), and dredged off Gough Island, lat. 40° 20′ S., long. 90° 56′ W., at a depth of 100 fathoms. Date, 22nd April 1904.

The colonies were growing on the horny axis of a Gorgonid Alcyonarian, and appear to have been lying untenanted for some time, for not only has the coenosarc almost wholly disappeared, but foraminifera frequently occur within the hydrothecæ, while barnacles and polyzoa, including a beautifully ringed, snake-like form, *Anguinaria spatulata*—a rare British species—occur growing on the colony.

Family Sertulariidæ.

Sertularella arborea, Kirchenpauer, 1884.

This species is represented by some colonies growing on lamellibranch shells, the largest reaching a height of 8 cm. The specimens possess the characteristics described by Hartlaub (1900):—Compound stems and branches; branches pinnate and alternate, arising beneath a hydrotheca and divided by slanting nodes into very *short, stout internodes*, each of which bears a hydrotheca; hydrothecæ adnate for about two-thirds of their length, with walls of unequal thickness and hints of *intracalycine teeth*; margin divided into *four small, equal teeth.* Gonotheca very long (about 3 mm.) and narrow, often smooth, sometimes with faint signs of ringing, usually bearing at the distal end four minute teeth, and always arising from between the internode and the side of the hydrotheca near the margin. The specimens show no variations which have not been noted by Hartlaub (1900).

Locality, etc.—Entrance to Saldanha Bay, Cape Colony; 25 fathoms. Date, 21st May 1904.

Sertularella contorta, Kirchenpauer, 1884.

Several specimens of this species have been obtained from two localities. They are bushy colonies reaching to a height of slightly over 7 cm., almost destitute of branches

near the base, but profusely branched distally. Except in the following unimportant details, the specimens agree with those previously described. While the annulations at the bases of the branches are well marked, the constrictions in the internodes are neither so frequent nor so distinct as those of former specimens. The gonangia closely resemble those described and figured by NUTTING (1904, p. 85). The annulations vary in number, in some cases disappearing altogether in the proximal portion of the gonangium. The teeth at the summit of the gonangium also vary in number; sometimes they seem to be absent, as in KIRCHENPAUER's specimen (1884), sometimes two are present, as described by NUTTING, but in the present specimens three is also an occasional number.

Localities.—(*a*) Falkland Islands, Port Stanley. Date, 8th January 1903. (*b*) Cape Pembroke; shore. January 1903 to January 1904.

It is interesting to note that the present specimens were found in the same locality as were those from which the original description of the species was made by KIRCHENPAUER some twenty years ago.

Sertularella filiformis, var. *reticulata*, n. var.

Several colonies referable to this species have been found, usually growing on polyzoon crusts, in two localities. Of the colonies, which are profusely branched and loaded with gonangia, those from locality (*a*) reach a height of from 5 to 6 cm. while those from (*b*) are considerably smaller. The hydrothecæ are adnate to the stem for 0·27 mm. and free for 0·15 mm., while at the opening their diameter is 0·15 mm. They have three teeth, thus differing from ALLMAN's (1888) description, where two broad cusps are mentioned, and agreeing with NUTTING's 1904) description of a portion of ALLMAN's specimen. The present specimens vary slightly from those described by NUTTING in habit and in gonangia. The majority of those from (*a*) and all the specimens from (*b*) have closely interwoven and anastomosed branches, and thus present a matted, net-like appearance.

Gonosome.—The gonangia arise from each side of and just below the hydrothecæ. They are top-shaped, 1·7 mm. long, with eight or nine large annular ridges, the widest portion occurring about the second or third ridge from the distal end, where the diameter, not including the ridge, is 0·7 mm. They are surmounted by a tube 0·45 to 0·5 mm. long, whose diameter gradually increases from base to margin, where it is 0·25 mm. wide.

Localities, etc.—(*a*) Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W.; 56 fathoms. Date, 1st December 1903. (*b*) Eight miles north of Dassen Island, Cape Colony; 35 fathoms. 18th May 1904.

Sertularella gayi, Lamouroux, 1821.

A strongly fascicled specimen 13 cm. high by 7 cm. broad is referable to this species. The general habit of the colony, with rigid stem 2 mm. in diameter

just above the base, and monosiphonic, roughly pinnate ramuli, is typical. The hydrothecæ are free distally for rather less than half their length, the free portion standing out from the stem almost at a right angle, and being marked on the upper side by a few rather indistinct annular rugosities.

Gonosome.—Not present.

Locality, etc.—Depth, 100 fathoms. Off Gough Island. Lat., 40° 20′ S.; long., 9° 56′ W. Date, 22nd April 1904.

Sertularella tenella (Alder, 1857).

Small specimens of this delicate colony some 7 mm. long have been found growing on *Synthecium robustum*. They are quite typical in appearance, agreeing with previous descriptions and figures.

The following are average measurements:—

Internodes.—Length from 0·55 to 0·8 mm.

Hydrothecæ.—Length, 0·5 mm.; widest diameter, 0·25 mm.; diameter at margin, 0·15 mm.

Gonosome.—Not present.

Locality, etc.—From off Burdwood Bank, lat. 54° 25′ S., long. 57° 32′ W., at a depth of 56 fathoms. Date, 1st December 1903.

Sertularella tricuspidata (Alder, 1856).

A slender, pinnately branched colony 7 cm. high. It lacks the profuse branching and matted appearance of a typical specimen of *S. tricuspidata*, but in other respects it agrees closely with the specific description.

Average Measurements.—Internodes: length, 0·75 mm. Hydrothecæ: height, 0·6 mm.; portion adnate, 0·35 mm.; portion free, 0·4 mm.; diameter at margin, 0·3 mm.

Gonosome.—Not present.

Locality, etc.—From off Burdwood Bank, lat. 54° 25′ S., long. 57° 32′ W., at a depth of 56 fathoms. Date, 1st December 1903.

Sertularella rectitheca, n. sp. (Pl. I. fig. 5.)

A small, delicate colony some 9 mm. high, growing on the stem of *Staurotheca reticulata*. The stem is slender and unbranched, divided for some distance by slanting nodes into short regular internodes 0·5 mm. long, and produced distally into a tubular tendril-like process which was attached to a portion of the Staurotheca colony. The internodes are much broadened half way up their length by a shoulder for the support of the hydrothecæ. These are alternate, cylindrical, about 0·5 mm. high by 0·15 mm. in diameter, adnate up to the distal end of the internode in which they arise, then free for the remaining third of their length. The hydrothecæ are straight, the free portion

being in the same line as the adnate, the whole axis lying practically parallel to the stem. The margins of the hydrothecæ are divided into three teeth, a small one on the adcauline edge, and two large and equal ones on the margin remote from the stem. The number of flaps in the operculum could not be counted.

Gonosome.—Not present.

Locality, etc.—Growing on *Staurotheca reticulata*, Scotia Bay, South Orkneys. Depth, 65 fathoms. Date, 25th March 1903.

Thujaria pectinata, Allman, 1888.

A single specimen some 6 cm. high almost completely enveloped in a dense polyzoon growth. The stem is unbranched and monosiphonic about 1 mm. across, and is divided into equal internodes, each of which bears three pairs of opposite hydrothecæ. A pair of opposite pinnæ arise from each internode, originating between the proximal and median pairs of hydrothecæ. On the pinnæ the nodes are quite distinct, being marked by a constriction (in ALLMAN'S figure they are scarcely indicated), and the hydrothecæ are arranged as on the stem—three pairs to each internode. The hydrothecæ are so closely approximated that the top of one touches the base of the next, but the "free membranaceous extension of the wall" has in every case been destroyed, leaving a rather ragged edge level with the general outline of the pinna. One of the pinnæ, instead of being thecate to the tip, was produced into a long, tubular, tendril-like process.

Gonosome.—Not present.

Locality.—Dredged at the entrance of Saldanha Bay, Cape Colony, in 25 fathoms. Date, 21st May 1904.

Synthecium robustum, Nutting, 1904. (Pl. I. fig. 6.)

About half-a-dozen specimens of this species have been dredged from the locality of Burdwood Bank. The average height is about 7 cm., but two specimens are 11 cm. high by 4 cm. broad, almost twice the size of the specimen described by NUTTING. The branches, which are regularly opposite, are simple in the majority of the specimens, but in some they rarely bear opposite branchlets; and not only in these branchlets, but even in the branches themselves, there is a distinct narrowing of the perisarc immediately above each pair of hydrothecæ. The hydrothecæ have frequently one or two annular striations—lines of reduplication—round their margins. Except in these details the trophosome agrees with NUTTING'S description.

Gonosome.—The gonangia differ somewhat from the dried specimens originally described. They are top-shaped, 2 mm. long by 1 mm. in diameter at the widest part. Distally they are strongly annulated, proximally they are almost smooth, while they are terminated by a low dome, the tubular neck of the original specimen being unrepresented.

Locality, etc.—Burdwood Bank. Lat., 54° 25′ S.; long., 57° 32′ W. Depth, 56 fathoms. 1st December 1903.

The occurrence in these specimens of branches sometimes simple and sometimes bearing pinnately arranged branchlets, appears to indicate that this character, upon which HARTLAUB founded his *S. chilense* (1905, p. 671), is rather a variation than a character of specific value.

Staurotheca, Allman, 1888 (modified).

Generic Character. Trophosome.—Hydrocaulus fascicled or unfascicled, bearing hydrothecæ in longitudinal rows and arranged in a series of transverse planes, each plane containing two or three hydrothecæ which exactly alternate with those in the planes above and below them.

Gonosome.—Gonangia simple capsules springing from the hydrocaulus and destitute of marsupium.

This genus, as described by ALLMAN, must be slightly modified to include the specimen described below. The alternate arrangement of the successive series of hydrothecæ remains constant, but the generic characters must be widened to include not only opposite hydrothecæ, but also hydrothecæ arranged in whorls of three.

Staurotheca reticulata, n. sp. (Pl. I. figs. 1, 1A, 1B.)

A portion of a branched hydroid colony 8 cm. in length by 4 cm. in breadth. The stem, which is 0·5 mm. in diameter, is unfascicled, and from it arise, at fairly regular intervals of 5 mm., alternate flexuous branches of the same thickness as the stem, which zigzags between their bases. Smaller branches arise from these main branches and anastomose so frequently, sometimes by means of short, tendril-like processes, that free ends are absent except towards the margin of the colony. In some cases the free ends develop hydrorhizal tubes. All the branches lie in one plane, and this, together with the flabellate form of the colony and the prevalent anastomosis, gives the whole a remarkable net-like appearance, the regularity of the meshwork, at least near the stem, being increased by the fact that the main branches on each side of the stem lie roughly parallel. The internodes are irregular, generally containing about three pairs of hydrothecæ in the older branches, while in the younger there is usually a hint of a node between each pair.

The hydrothecæ are placed in longitudinal rows along the stem and branches. In the majority of the branches there are four rows, the hydrothecæ being arranged in opposite pairs, which are placed alternately at right angles with one another. Sometimes there are six rows—the hydrothecæ in this case being placed in a succession of transverse planes, each plane containing three equidistant hydrothecæ, which exactly alternate with those in the planes immediately above and below them. The hydrothecæ themselves are cylindrical and deep, with a circular orifice and a smooth margin marked

sometimes by one or two lines of growth. They are 0·5 mm. in height, and for 0·4 mm. of this distance they are adnate, the free portion curving outwards from the stem.

Gonosome.—The gonangia are ovoid, 0·7 to 0·8 mm. long, and 0·45 mm. in diameter at the widest part, narrowing proximally and terminated distally by a circular orifice at the end of a short bulging prominence. They lie closely apposed to the stem for the greater part of their length, but can easily be detached, and arise on each side of, and just below, a hydrotheca. Thus although one or two gonangia most commonly occur at one level, the full complement at a plane containing a pair of hydrothecæ is four, two to each hydrothecæ.

The colony is of a horn brown colour.

Locality, etc.—Obtained from a gripper on a sounding wire from Scotia Bay, South Orkneys. Depth, 65 fathoms. Date, 25th March 1903.

Family Plumulariidæ.

Aglaophenia dichotoma (Johns.), Kirchenpauer, 1872. (Pl. III. figs. 2, 2A, 2B, 2C.)

A large number of branched, fan-shaped colonies, 10 cm. high by about 7 cm. broad, with monosiphonic stems. The following details supplement Kirchenpauer's rather meagre description :—The branching, which is characteristic, is strictly dichotomous. The stem and branches are divided into short regular internodes 0·3 mm. long, and from a nematophore-bearing process on each of these a hydroclade arises. The *hydroclades*, which are alternate and closely approximated, are borne on the front of the stem and leave it at an angle of about 45°. They also are divided into short regular internodes 0·3 mm. in length, each with two strong septal ridges extending almost around their walls, one opposite and in line with the intrathecal septum, the other at the level of the bases of the supracalycine nematophores. The *hydrothecæ*, which are closely approximated and obconical, are tilted forward from the stem, the distal portion apparently being free. Their margin, which is not expanded or flaring, is divided into nine teeth, the anterior three being slightly larger and sharper, the middle one bent a little backwards. The intrathecal ridge is strong and oblique, in the same line as the corresponding internodal ridge, and reaching to the opposite wall of the hydrotheca. The supracalycine *nematophores* are not quite tubular. They are large and bulging, but do not reach to the margin of the hydrotheca, while the mesial nematophore, which is extremely narrow near the base but becomes wider distally, just reaches the level of the margin, the distal third of its length being free. The process arising from the stem and branch internodes, upon which the hydroclades are borne, bears about five nematophores similar in structure to those on the hydrotheca. The arrangement also is similar, one being median and proximal, while two are lateral and near the distal end of the process, but there are in addition a lateral and a basal pair.

Gonosome.—The corbula is oval, flattened laterally, 2 mm. long by 1 mm. in

greatest diameter. It has five pairs of adnate costæ, each bearing from ten to twelve not quite tubular denticles along its length and an apparently unpaired, partly free, costa at the proximal end. On the corbula peduncle there is one hydrotheca.

Locality, etc.—The colonies were growing on a sponge, and were dredged at the entrance to Saldanha Bay, Cape Colony, in 25 fathoms of water. Date, 21st May 1904.

Plumularia echinulata, Lamark, 1836.

Several colonies, the largest 3 cm. in height, were found growing on sponges in the same locality as *P. pinnata*. The specimens differ somewhat from the type described by HINKS (1868) but seem to form a connecting link between *P. echinulata*, type and *P. echinulata*, var. *pinnatöides* of BILLARD (1904, p. 191 *et seq.*). The following points indicate a close relationship to the latter:—Stem internodes in the proximal portions of the colony sometimes bearing two hydroclades, while in the distal internodes, and more generally throughout the colony, only one hydroclade per internode is the rule; intermediate internodes in the hydroclades absent in the specimens examined; supracalycine sarcostyle unprotected by a nematotheca, as described by HINKS; hydrothecæ deep; gonangia borne on stem. On the other hand, the fact that the margin of the hydrotheca does not reach the level of the succeeding node, and the presence of well-marked and frequent spines on the gonangia, indicate affinities with BILLARD'S *type*.

The state of the material prevented observations on the condition of the axillary nematophores from being made.

Locality, etc. — Growing on sponges, coaling jetty, Cape Town Docks. May 1904.

Plumularia magellanica, Hartlaub, 1905. (Pl. III. fig. 1, 1A.)

The specimens collected by Mr BRUCE differ somewhat in the structure of their hydroclades from the specimens of this peculiar species described by HARTLAUB, but the difference is not of specific value. As in HARTLAUB'S case, material is scarce.

The most complete colony is 15 mm. in height, and consists of a stem 0·15 mm. in diameter, divided by straight nodes into irregular internodes, each of which bears near its middle a single hydroclade. *The hydroclades* arise alternately from the stem nodes and are comparatively short — about 1 mm. They are set upon a small process of the stem, from which the first thecate internode is separated by a narrow, somewhat ring-like, athecate internode with slanting nodes. The thecate internodes are narrow at the base, and gradually widen distally until they finally seem to end in a rather shallow cup with expanded walls. From below this cup, and free from it, there arises in the distal portions of the colony a single short process, which bears again an expanding thecate internode from beneath whose hydrotheca another free process is given off, and so on, until each hydroclade bears from two to four or even five hydrothecæ. The

marked angle at which each thecate internode lies with regard to the one preceding it, gives these simple distal hydroclades a helicoid-cyme-like appearance. In the proximal hydroclades—and here our specimens differ from HARTLAUB's—*two processes* arise below and at the opposite sides of the first hydrotheca, each of which bears a thecate internode, so that after the first hydrotheca the hydroclade possesses two diverging branches each similar to the simple distal hydroclades. Since the double hydroclades arise *laterally and not dorsally*, as HARTLAUB describes, from their internode, it follows that their origins lie in a plane at right angles to the plane of the primary stem processes. The *hydrothecæ* are shallow, with delicate, slightly expanded walls, and smooth margins. They appear to terminate the internode which bears them, are fixed only by their bases to their internode, and their walls are free. A single delicate, shovel-like nematophore lies in the centre of the internode beneath each hydroclade.

Gonosome.—Not observed.

The structure of the whole colony is extremely delicate. In some cases the hydrothecal and internodal walls collapsed in process of mounting for microscopic examination.

Locality, etc.—Growing on a sponge, Port Stanley, Falkland Islands. 3rd February 1904.

Previous Localities.—South of Tierro del Fuego and Island Pictou, Tierro del Fuego Archipelago.

Plumularia pinnata, Linnæus, 1758.

A number of colonies, the largest only about 4 cm. high, occur on sponges and on lamellibranch shells. The colonies agree with HINKS's description. The following variations were noted in the specimens:—Generally the number of hydroclades per internode is two, but on a number of the distal internodes only one hydroclade occurs. The presence of a basal athecate internode at the origin of each hydroclade, as described by BILLARD (1904, p. 204), was noted, but between the thecate internodes no intermediate athecate internodes were observed.

Gonosome.—While the proximal, and therefore the older, gonangia assumed the spinous form figured by HINKS (1868, Pl. 65), the distal, younger gonangia were somewhat cup-like, with a truncated appearance, due to the inversion of the topmost portion of the gonangium, which, at first inverted, apparently becomes everted in the later stages of growth.

Locality, etc.—Growing on sponges and on lamellibranch shells, coaling jetty, Cape Town Docks. May 1904.

Plumularia unilateralis, n. sp. (Pl. II. figs. 1, 1A, 1B, 1C.)

The specimens for which this species has been formed are small, averaging only 2 cm. in height, with simple recurved stems divided by slanting nodes into regular internodes, in general 0·4 mm. in length, but rather longer towards the base. From the

middle of each internode there arises a single hydroclade. In no case has more than one hydroclade per internode been seen. The *hydroclades*, which are set on short processes of the stem internodes, lie alternately in two planes, these planes being so set forward that the hydroclades appear to arise from only one side of the stem. They leave the stem at acute angles (30° to 45°), and are divided into equal internodes 0·25 mm. long, each of which bears a hydrotheca—one small triangular athecate internode separating the first thecate internode from the stem process In some cases secondary hydroclades are developed from the side of a hydroclade internode at the level of the base of the hydrotheca. No internodal septæ are present, but the internode bulges proximally to form a support for the hydrotheca. The *hydrothecæ* are cup-shaped, moderately deep, even-rimmed, and for a short distance distally they are free from the internode. They are closely approximated, the margin of a hydrotheca being on a level with the succeeding node. *Nematophores* are absent from the stem, from the stem processes, and from the athecate internodes at the origin of the hydroclades, but one small, shovel-shaped nematotheca occurs in the median portion of the internode just below each hydrotheca, while in the angle between the hydroclade and the free rim of the hydrotheca is a median, unprotected sarcopore.

Gonosome.—Gonothecæ about 1 mm. in length occur in parallel rows along the stem, apparently arising on the inner side of the hydroclade-bearing processes. They are ovate, with somewhat flat tops, and are very shortly stalked. The gonothecæ are seldom smooth, the walls being generally strengthened by seven regular longitudinal ridges, which terminate distally in one or two more or less pronounced spines.

Locality, etc.—Growing on a sponge from the entrance to Saldanha Bay, Cape Colony; 25 fathoms. Date, 21st May 1904.

Antennularia hartlaubi, n. sp. (Pl. III. fig. 4, 4A, 4B.)

Colonies growing on a sponge in thick bunches, with thick fascicled stems which, about 1 cm. from the base, break up irregularly into smaller, still fascicled branches, these finally breaking up into long simple twigs. The latter are divided by straight nodes into regular internodes 0·5 mm. long, each of which bears three equally distant hydroclades so arranged that those on one internode exactly alternate with those on the internodes above and below, a hexastichous arrangement thus being produced. The *hydroclades* are borne on stout processes of the branch internodes 0·15 mm. long, and are divided into unequal internodes which are alternately long and thecate and short and athecate—two athecate internodes separating the first thecate internode from the supporting process. Sometimes, however, two athecate internodes are developed between a hydrotheca-bearing pair. Each internode is marked by two strong internal septa, one proximal, the other distal; but in the longer internodes two more are sometimes developed, one opposite the base of the hydrotheca, the other a little lower. The *hydrothecæ* are shallow, even-rimmed, resting on a broad ledge of the internode

and free for a short distance distally. The *nematophores*, of the usual trumpet-shaped type, have an internal septum which gives them a two-jointed appearance and are arranged as follows :—Three on each thecate internode, two lateral and distal, and reaching a considerable distance above the level of the hydrotheca margin, the other median and proximal and arising just above a slight bulge in the internode; one on each athecate internode, except where two such internodes are developed in succession, when the proximal one is unprotected; on the branches there are two lateral nematophores on the hydroclade-bearing process and one in the angle between this and the branch, but in the next highest internode.

Gonosome.—Not observed.

Locality, etc.—Entrance to Saldanha Bay, Cape Colony, in 25 fathoms. 21st May 1904.

The present specimens approach in general structure *A. decussata*, Kirch. (1876, p. 55), *A. johnstoni*, Kirch. (1876, p. 55), and *A. irregulares*, Quelch (1885, p. 8), for in the first and last of these the hydroclades, although generally two in number per internode, may vary from two to three or even four. In our specimens the hexastichous arrangement appears to be constant, and the species is distinguished from those mentioned above in having exceedingly strongly developed internodal septa.

We have named the above form after Professor Cl. Hartlaub of Heligoland, author of the report on the Belgian Antarctic Expedition hydroids, to whom we are indebted for occasional assistance.

Antennopsis scotiæ, n. sp. (Pl. III. figs. 3, 3A.)

Two much weather-beaten colonies of a pale brownish colour, growing on a sponge fragment and reaching a height of 9 cm. and 4 cm. respectively. Both the colonies are badly weathered; the smaller is overgrown for half its length by the sponge, while the remaining portion is destitute of hydroclades. Here and there at irregular intervals a branch springs from the main stem, but without any definite arrangement. Of the larger specimen about 5 cm. are free from the encircling sponge, and on this almost bare surface a few hydroclades occur. The stem and branches are strongly fascicled, about 2 mm. in diameter, but the coenosarc shows no signs of caniculation (Nutting, 1900, pp. 68 and 72). The *hydroclades* arise irregularly from all sides of the stem, springing from the outer tubes of the fascicle. Proximally they have from three to six athecate internodes separated by straight nodes, the distal of these, and sometimes that beneath it, being greatly elongated and bearing a number of nematophores varying from two per joint to five on a single long internode. Above this athecate portion the hydroclade is divided by alternate slanting and straight nodes into fairly regular internodes, every alternate one of which bears a hydrotheca. The *hydrothecæ* are stoutly campanulate and large, 0·22 mm. in length by 0·22 to 0·25 mm. in greatest diameter, with entire rim and oblique opening, adnate up to the distal end of their own internode, and afterwards free—the free portion lying over against the intermediate internode, the rim reaching the level of the proximal end of the next hydrotheca-

bearing internode. They are thus closely approximated. The *nematophores* have a widely expanded, trumpet-shaped mouth, and besides those already mentioned, there are three on each hydrotheca-bearing internode, one median and proximal, standing on a slight angle of the internodal perisarc, two lateral, each borne on a process which rests against the side of the hydrotheca. Only one nematophore occurs on each intermediate internode.

Gonosome.—Not observed.

Locality, etc.—Dredged at the entrance of Saldanha Bay, Cape Colony, in 25 fathoms. Date, 21st May 1904.

The general architecture approaches that of *Antennopsis fascicularis* (ALLMAN, 1883, p. 24), but there are differences in the proximity of the hydrothecæ and in the number and distribution of the nematophores.

We have named this species after the *Scotia*—the ship of the Scottish National Antarctic Expedition.

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EXPLANATION OF PLATES.

Plate I.

1.	*Staurotheca reticulata*, n. sp.	Nat. size.
1A.	,, ,,	Portion of stem and branch showing hexastichous and decussate arrangements of hydrothecæ.
1B.	,, ,,	Portion of branch with gonangia.
2.	*Campanularia*, sp.	
3.	*Halecium interpolatum*, n. sp.	Nat. size.
4.	*Grammaria magellanica*, Allm.	Nat. size, showing gonosome cluster.
4A.	,, ,,	Surface of gonosome cluster.
5.	*Sertularella rectitheca*, n. sp.	
6.	*Synthecium robustum*, Nutt.	Gonangium.
7.	*Hebella striata*, Allm.	Hydrotheca not completely ringed.
8.	,, var. *plana*, n. var.	

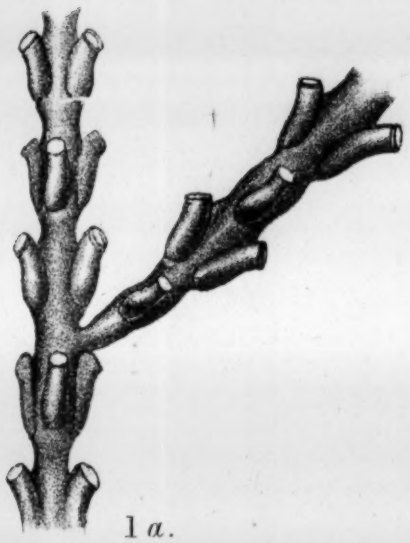
Plate II.

1.	*Plumularia unilateralis*, n. sp.	Nat. size, growing upon a sponge fragment.
1A.	,, ,,	Stem with hydroclades.
1B.	,, ,,	Gonangia.
1C.	,, ,,	Portion of hydroclade with hydrothecæ.
2.	*Brucella armata*, n. gen. et sp.	Nat. size, showing coppinia cluster.
2A.	,, ,,	Surface of coppinia cluster.
2B.	,, ,,	Portions of a fascicled and an unfascicled branch, with a creeping polyzoon—*Anguinaria spatulata*.
2C.	,, ,,	Hydrothecæ.
3.	*Halecium interpolatum*, n. sp.	Branch, with hydrothecæ, ending in stolons.
4.	*Halecium tenellum*, Hinks.	Showing attachment of hydranth within hydrotheca.

Plate III.

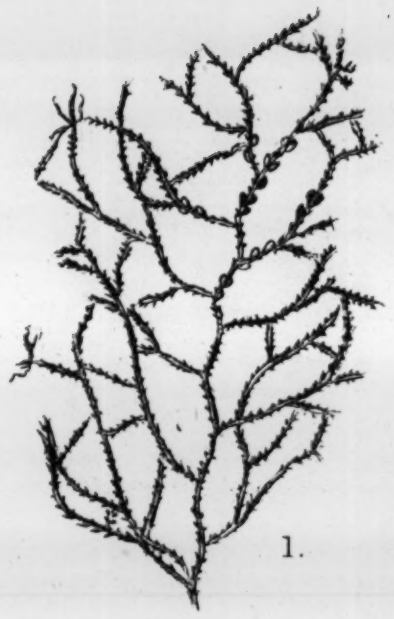
1.	*Plumularia magellanica*, Hart.	
1A.	,, ,,	Origin of a double hydroclade.
2.	*Aglaophenia dichotoma* (Johns.).	Nat. size.
2A.	,, ,,	Corbula.
2B.	,, ,,	Hydrothecæ.
2C.	,, ,,	Portion of stem, showing origin of hydroclades.
3.	*Antennopsis scotiæ*, n. sp.	Nat. size, partially encircled by a sponge.
3A.	,, ,,	Hydroclade with hydrothecæ.
4.	*Antennularia hartlaubi*, n. sp.	Nat. size.
4A.	,, ,,	Hydroclade with hydrothecæ.
4B.	,, ,,	Stem showing hexastichous arrangement of hydroclades.

RITCHIE: "SCOTIA" HYDROIDS. — PLATE I.



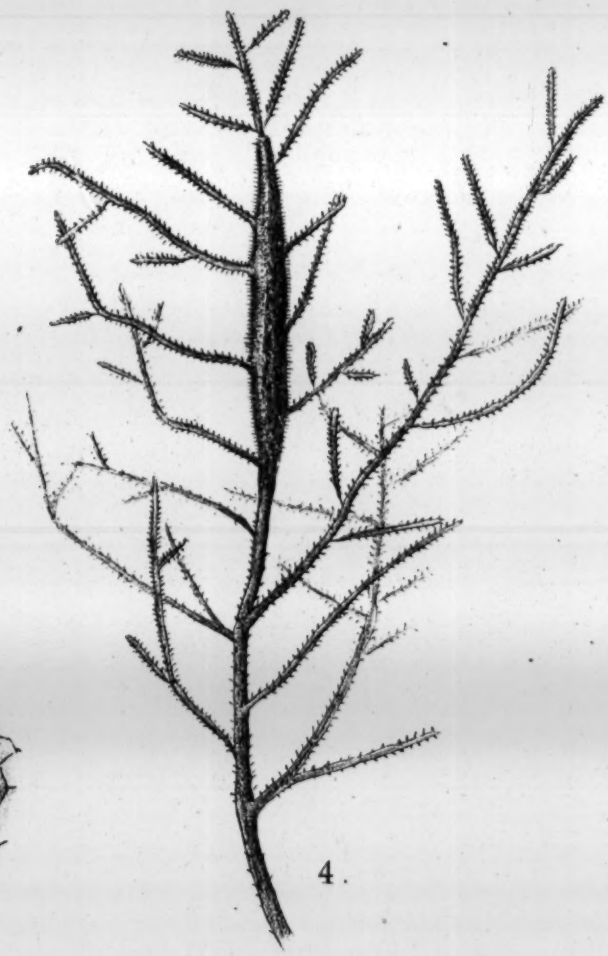
1 *a*.

2.



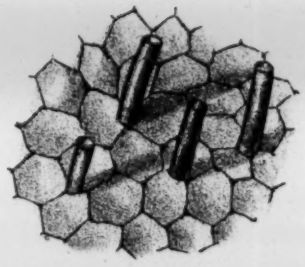
1.

6.



4.

5.



4 *a*.

3.

7.

8.

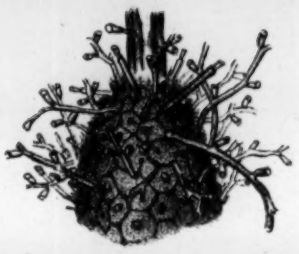
1 *b*.

Jas. Ritchie, del.

M'Farlane & Erskine, Lith. Edin.r

RITCHIE: "SCOTIA" HYDROIDS. — PLATE II.

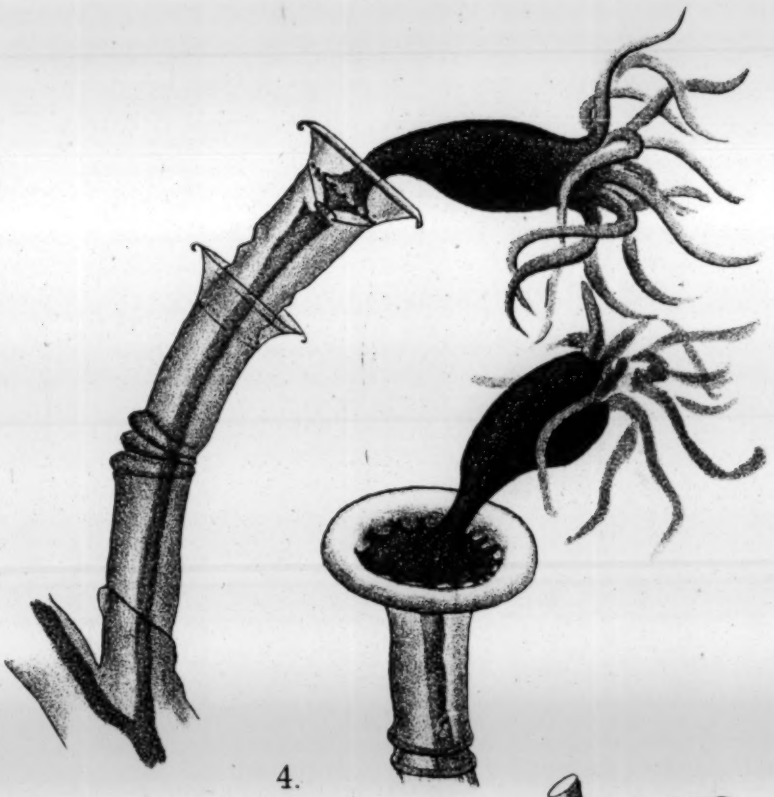
1 *a*.



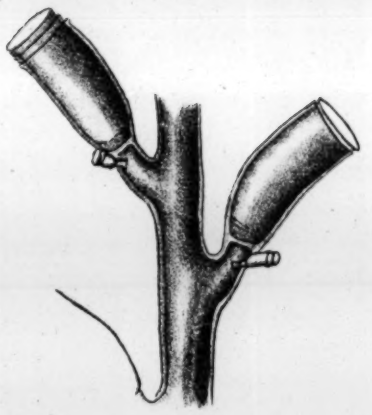
2 *a*.

2.

3.



4.



2 *c*.

1 *b*.

1.

2 *b*.

1 *c*.

M'Farlane & Erskine Lith. Edin.r

RITCHIE: "SCOTIA" HYDROIDS.— PLATE III.

1.

2 *a*.

2.

4 *a*.

4.

3.

3 *a*.

1 *a*.

4 *b*.

2 *b*.

2 *c*.

Jas. Ritchie, del.

Wm. Wallace & Erskine, Lith. Edin.

XIX.—Magnetization and Resistance of Nickel Wire at High Temperatures. Part II.

By Professor C. G. Knott, D.Sc.

(Read December 17, 1906. MS. received same date. Issued separately April 1, 1907.)

The experiments which form the subject of the present communication were carried out two years ago, and supplement results already published.* A brief note of some of the results was read before the Society in June 1904, and was also read before the British Association Meeting at Cambridge in August of the same year.

The previous paper discussed the effect of high temperature on the relation between electrical resistance and magnetization when the wire was magnetized longitudinally, that is, in the direction in which the resistance was measured.

The present results have to do with the effect of high temperature on the relation between resistance and magnetization when the magnetization was transverse to the direction along which the resistance was measured.

Since the publication of my note in 1904, an interesting paper by W. E. Williams, B.Sc., on the same subject, has appeared in the *Philosophical Magazine* for January 1905. His work has to do chiefly with resistance change in the direction of magnetization, and covers a good deal of the ground I had mapped out for my own investigation, so that it is no longer necessary for me to pursue that line of inquiry. Mr Williams was able to work up to much higher fields than I was able to obtain with my form of apparatus, and one novel result obtained by him was the reversal of the sign of the resistance change in high transverse fields at ordinary temperatures. He does not seem, however, to have studied the effect of transverse fields at high temperatures. Some of his results in the high-temperature experiments in longitudinal fields have a resemblance to the curious effect communicated in my note of 1904. This peculiarity I now desire to give in detail.

As mentioned in the former paper, my first attempts to measure the change of resistance of nickel wires due to transverse magnetization were unsuccessful, simply because of the thinness of the wire in the direction of the magnetizing force, and because the fields attainable were too small. By inserting a flat coil of nickel wire in the short air-gap of an electromagnet, I was able to obtain measurable changes. The wire was carefully wound in a flat coil between two mica strips, the contiguous parts of the coil being kept apart by asbestos thread coiled in between.† The coil was enclosed

* "Magnetization and Resistance of Nickel Wire at High Temperatures," *Trans. Roy. Soc. Edin.*, vol. xli. pp. 39–52, 1904.

† It is of great importance to make sure that, when the flat nickel coil is magnetized, the lines of force are directly transverse. A slight component of field *along* the wire brings in the longitudinal effect which may, under certain conditions, affect the sign of the change of resistance, especially in low fields. It was only after several trials that a satisfactory flat coil was obtained.

in an anti-induction wound coil of asbestos-covered wire which could be kept at any desired temperature by means of a suitable current passed through it. The resistance of the nickel wire itself served as thermometer.

The nickel wire formed one arm of a Wheatstone bridge; and the change of resistance, when any given field was applied, was measured by deflection on a delicate galvanometer, the constant of which was determined from time to time by the deflection produced when a known change of resistance was made in one of the other arms of the bridge. The method was in fact identical with that already described in my earlier papers.

The electromagnet was standardised by means of a bismuth coil placed in various positions within the air-gap, and an estimate made of the average fields across the area occupied by the nickel coil for certain definite values of magnetizing current. The fields for the currents used in the experiment were then determined graphically by interpolation.

Each separate experiment was carried out in the following manner:—A suitable current was passed through the heating coil surrounding the nickel wire; and when the temperature became steady, as indicated by the steadiness of the resistance of the nickel, the real measurements began to be made. For every such temperature reached, the nickel coil was subjected to various magnetizing fields and the corresponding changes of resistance measured. A curve was then constructed on section paper in the usual way, showing the relation between magnetizing force and resistance change. This was done for each temperature; and from the graphs so obtained a new set was formed giving the relation between temperature and resistance change due to the application of given chosen fields.

The individual measurements in the order in which they were obtained are given in the appendix; and in the table given here, the results are arranged in a form which shows at a glance the peculiarity already referred to. The most striking results are also indicated graphically in the diagram.

The experiments on which this table is based were all performed between 25th May and 14th June 1904, and the date is given in the first column. The second column contains the resistances of the wire at the various temperatures, which were indeed measured by means of the corresponding resistances, and are entered in the third column. The remaining six columns contain the resistance changes, estimated per 100,000, produced by the six fields the values of which are entered along the tops of the columns. The total change of resistance of the wire in any particular case can be found by dividing by 100,000 and multiplying by the resistance as given in the second column.

Running our eye down the column headed by field 3800, we see that the percentage change of resistance due to the application of this field steadily falls off as the temperature rises until the temperature of 260° C. is reached. Did the rate of fall continue constant, the change of resistance due to magnetization would vanish about 360°. Instead of so

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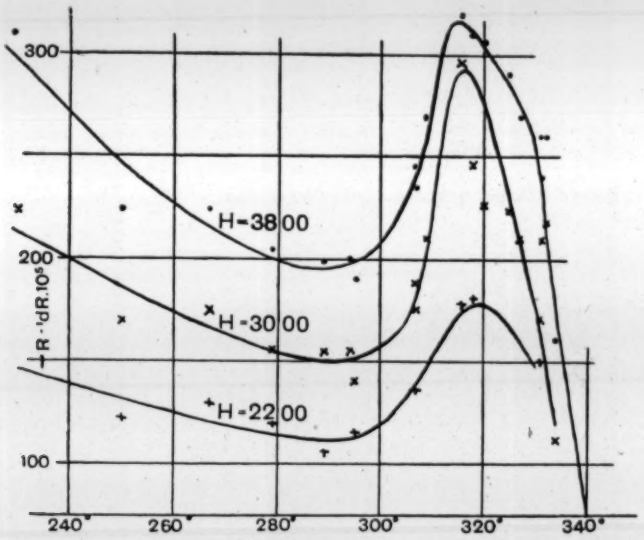
Change of Resistance (Decrease) per 100,000 *of Nickel Wire in Various Transverse Fields at Different Temperatures.*

Date. May or June.	Resistance of Wire.	Temp. Centigrade.	Field.					
			3800	3000	2200	1200	900	500
27	0·545	11°	800	465	240	50	20	9
26	0·555	12	740	455	230	20		
25	0·56	12	800	480	260	75	40	10
8	0·556	12	779	490	250	50		
2	0·556	12	760	480	240	45		
9	0·610	33	750	452				
9	0·629	45	750	460				
9	0·674	55	735	445				
14	0·81	102	645	420				
26	0·864	120	590	370	310	20		
8	0·896	130	577	377				
8	1·043	174	453	321				
26	1·055	178	460	318	182	46		
25	1·059	180	450	320	182	46	30	7
8	1·079	185	437	303				
25	1·104	193	420	300	170	30	5	−3
8	1·135	198	397	286				
1	1·147	200	380	280				
3	1·158	202	380	282				
27	1·160	203	390	276	170	35		
3	1·276	224	315	248				
31	1·284	226	315	240	150	20		
1	1·295	228	325	246				
3	1·301	229	310	224				
27	1·419	250	225	170	123	40		
30	1·490	267	225	174	130	41		
31	1·532	279	205	155	120	40		
30	1·594	289	198	148	106	41		
1	1·609	294	200	155				
31	1·621	295	190	140	115	55	30?	15?
31	1·688	307	235	175	137	59	35?	16?
1	1·690	307	245	187				
2	1·698	309	269	211				
31	1·743	316	318	296	178	98	70	39
1	1·752	318	310	247	180	96	70	37
2	1·760	320	305	227				
1	1·783	325	290	225				
2	1·795	327	269	211				
26	1·814	331	260	210	150	80		
27	1·815	331	240	170	110	77	63	40
30	1·824	332	260	208	153	78	55	27
2	1·828	334	161	112				
27	1·877	344	39					
2	1·878	345	39					
2	1·908	360	4					
1	1·943	384	54					

continuing to diminish, however, the resistance change passes through a minimum as the temperature rises through 295° and thereafter experiences an abrupt rise in value, reaching a sharp maximum at 310°. At higher temperatures the value of the resistance change falls off rapidly to a comparatively low value at 344°. At this temperature, as is well known, the nickel loses its strong magnetic qualities and becomes practically a non-magnetic metal.

The peculiarity was first noticed in the experiment of 27th May, when, by application of fields about 3700 (see Appendix), I obtained for the resistance changes at 331°, 250°, and 203° the values 226, 213, and 376. That is to say, the smallest effect was obtained with the intermediate temperature. The same result was given with the other fields used. The first impression was that this quite unexpected result was due



The ordinates measure in the units indicated either Decrease of Resistivity or Increase of Conductivity.

to some error of experiment. Accordingly, I proceeded to make a great many other experiments so as to get as many measurements as possible in the neighbourhood of the minimum and maximum points. The experiment of 2nd June (see Appendix) is particularly instructive. To show how closely the various points cluster along the respective curves, I have plotted on an enlarged scale those parts which lie between the temperatures 240° and 344°.

The effect is undoubted in the three highest fields. It is also hinted at in the lower fields; but the smallness of the effects in these lower fields make the errors of observation more conspicuous, and the digits in the numbers tabulated may be in error easily by three or four.

The question at once suggests itself as to whether any analogous peculiarity can be detected in other electrical and magnetic properties of nickel. Thus, to take the very simplest case, is there any peculiarity in the relation between permeability and temperature in the neighbourhood of the temperatures 260° to 300°? According to TAIT's dis-

covery, there is a marked change in the Thomson Effect in nickel about these temperatures, and it is conceivable that peculiarities may be detected in the same region if definite search is made for them.

Accordingly I asked Miss Eveline MacLaren, a student working in the Physical Laboratory, to make a search for such a peculiarity. To this end a fairly long nickel wire was coiled seven times on itself and made the core of an anchor ring coil. Four separate coils were wound round it: two for magnetizing purposes, one for heating to various temperatures, and one for measuring the induction ballistically. The heating coil was wound anti-inductively, and all the wires were insulated with asbestos. The temperature of the nickel wire in any experiment was measured by the resistance of the wire. The investigation was carried out only between the limits of temperature already indicated; for there was nothing to be gained by repeating experiments which have already been done on the relation of permeability and temperature. I give the results at the end, although no peculiarity of the kind looked for was observed. It should be noted, however, that in these experiments we are dealing with comparatively weak *longitudinal* fields, and not with fairly strong *transverse* fields.

The lowest temperatures used in these experiments are just low enough to show the maximum reached by the induction in given fields as the temperature rises from about 200° to 240° C. The induction and permeability fall off very rapidly as the temperature of 320° C. is approached, and there is a suggestion that the temperature at which magnetic permeability becomes unity depends to some extent upon the magnetizing force applied. There is, however, no hint of anything peculiar corresponding to the effect described above.

As noted above, Mr WILLIAMS obtained, in high longitudinal fields at high temperatures, a result somewhat resembling the effect discussed in this paper. At the higher temperatures the curves showing the relation between longitudinal field and resistance increase had each a distinct maximum, dipping down towards the axis in the higher fields. At temperature 328° the curve cut the axis at field 630, so that the resistance change became decrease in higher fields. At temperatures 334° and 345° the curves cut the axis at fields 230 and 120 respectively, and the resistance decrease attained considerable values in the highest fields. At temperature 355°, however, the curve lay wholly below the axis, but very close to it throughout the whole range of magnetizing force. When the results are shown by means of curves for constant fields, giving the relation between resistance change and temperature, we find that in field 50 the change of resistance is always increase and falls off to very small values as temperature 350° is approached. On the other hand, in field 800 the resistance change is increase up to temperature 326°, becomes decrease for higher temperatures, passing through a minimum (maximum decrease) about temperature 340°, and thereafter diminishing numerically to very small values as 370° is approached.

That is to say, the change of resistance due to the application of certain longitudinal fields passed through a minimum value before finally vanishing at the highest tempera-

tures. My result with the transverse field is that the decrease of resistance, or the increase of conductance, passes through a minimum and then through a maximum before it vanishes in the highest fields.

We have therefore an indication that, at a temperature a little below that at which the nickel loses its magnetic susceptibility, the conductance becomes peculiarly sensitive to the influence of magnetizations, especially when the magnetizing force is considerable.

If we try to apply to the phenomenon the electron theory which Professor J. J. Thomson has used with great ingenuity, we are compelled to assume that electrons suddenly acquire more freedom of motion or greater ease of disentanglement at a temperature of 320° or so. This may be due to a change of orientation of the groups of magnetic molecules between which the electrons pass, or it may be due to removal of deflecting forces acting on the electrons. It may be safely assumed that the phenomenon is closely related to the change of sign of the Thomson Effect as discovered by Tait in 1873. It is quite within the limits of probability that the breaking up of groups, and the rearranging in stabler configurations as the temperature rises through a particular value, may be accompanied by a greater freedom of electronic convection.

APPENDIX.

Resistance change (dR/R) in nickel wire of resistance R when magnetized transversely to the direction in which resistance is measured by application of field H at various temperatures which are indicated by the resistance R. Each measured change depends on fifteen distinct readings, and the mean error is attached to the numbers here tabulated.

Date 1904.	R.	H.	$\frac{dR}{R}\times10^5$	Date. 1904.	R.	H.	$\frac{dR}{R}\times10^5$	Date. 1904.	R.	H.	$\frac{dR}{R}\times10^5$
May 25	0·56	3820	804 ± 12	May 27	1·814	3700	226 ± 2	June 1	1·690	3710	239 ± 6
		3390	639 ± 4			2930	163 ± 2			2930	182 ± 2
		2980	469 ± 7			2180	110 ± 2		1·752	3700	309 ± 10
		2350	286 ± 8			1210	78 ± 2			2920	238 ± 3
		1760	171 ± 7		1·419	3690	213 ± 8			2170	179 ± 2
		1230	78 ± 3			2920	163 ± 8			1200	97 ± 5
		920	44 ± 2			2170	123 ± 6		1·783	3700	281 ± 9
		610	25 ± 2			1200	39 ± 5			2920	219 ± 11
		410	14 ± 2		1·160	3700	376 ± 8		1·943	3700	53 ± 47
	1·059	3760	442 ± 5			2930	261 ± 12	June 2	0·556	3810	761 ± 1
		3350	388 ± 10			2170	167 ± 0			2980	470 ± 1
		2950	310 ± 9			1210	33 ± 8			2340	277 ± 3
		2240	190 ± 2	May 30	1·490	3740	220 ± 7			1230	49 ± 8
		1200	46 ± 1			2950	170 ± 1		1·908	3700	4 ± 2
		610	12 ± 3			2250	132 ± 4		1·878	3700	72 ± 12
		400	6 ± 3			1220	42 ± 5		1·828	3700	286 ± 1
	1·104	3730	409 ± 5		1·594	3730	193 ± 13			2930	206 ± 10
		3310	343 ± 0			2940	145 ± 6		1·795	3700	265 ± 5
		2930	287 ± 3			2240	109 ± 3			2930	195 ± 6
		2240	176 ± 2			1210	45 ± 3		1·760	3700	294 ± 2
		1680	93 ± 4		1·824	3720	254 ± 12			2930	220 ± 4
		1200	28 ± 0			2930	179 ± 3		1·698	3700	264 ± 3
		900	5 ± 2			2180	151 ± 2			2930	208 ± 1
		600	3 ± 0			1210	79 ± 5	June 3	1·301	3750	307 ± 0
May 26	0·555	3400	604 ± 4			880	53 ± 1			2940	223 ± 11
		3800	741 ± 2			390	18 ± 1		1·276	3730	308 ± 5
		2980	447 ± 5	May 31	1·743	3700	309 ± 13			2940	232 ± 15
		2340	259 ± 1			2930	239 ± 7		1·158	3730	374 ± 11
		1750	134 ± 8			2170	177 ± 2			2940	275 ± 7
		1230	37 ± 7			1200	98 ± 5	June 7	1·135	2970	280 ± 4
	0·864	3770	574 ± 1		1·688	3700	229 ± 10			3760	391 ± 4
		2970	360 ± 8			2930	171 ± 7		1·078	3750	429 ± 4
		2270	221 ± 3			2170	136 ± 1			2950	295 ± 4
		1230	27 ± 3			1200	59 ± 4		1·043	3750	444 ± 12
	1·055	3770	450 ± 8		1·723	3700	185 ± 12			2960	314 ± 7
		2960	305 ± 8			2910	148 ± 5		0·896	3740	558 ± 11
		2270	192 ± 3			2160	114 ± 10			2960	368 ± 24
		1230	33 ± 1			1180	50 ± 3	June 8	0·556	3800	779 ± 1
	1·814	3730	260 ± 0		1·532	3680	199 ± 5			3370	633 ± 0
		2940	205 ± 3			2910	151 ± 3			2930	469 ± 2
		2250	159 ± 2			2170	117 ± 7			2340	275 ± 1
		1220	83 ± 2			1200	38 ± 1			1230	48 ± 5
May 27	0·545	3700	761 ± 13		1·284	3700	305 ± 1	June 9	0·629	3780	746 ± 6
		2980	462 ± 10			2920	234 ± 5			3360	617 ± 11
		2360	275 ± 4			2160	151 ± 6			2980	455 ± 4
		1230	53 ± 9			1200	20 ± 5		0·610	3770	745 ± 6
		920	22 ± 4	June 1	1·147	3760	390 ± 6			2970	446 ± 1
		610	12 ± 5			2970	277 ± 4		0·674	3770	726 ± 50
		410	5 ± 1		1·295	3750	320 ± 3			2960	438 ± 17
	1·877	3730	38 ± 0			2940	240 ± 6		0·81	3760	633 ± 2
					1·609	3730	195 ± 1			2970	404 ± 1
						2930	150 ± 0				

Magnetic Induction and Permeability, both Total and Residual, of Nickel Wire at Various Temperatures in Various Fields.

Resistance of Wire.	Temperature of Wire.	Magnetic Field.	Total.		Residual.	
			Ind.	Perm.	Ind.	Perm.
2·13	16°					
7·08	336	21·4	200	8	0	0
6·98	331	18·04	250	12	50	4
6·85	324	18·2	882	50	366	21
6·77	320	18·08	1298	71	716	42
6·52	308	18·08	4227	233	3012	166
6·24	296	18·08	5824	320	4393	245
5·98	284	18·04	7604	420	5425	300
5·73	268	18·04	8370	462	6124	341
5·54	258	18·04	8902	495	6560	362
5·13	235	18·08	9170	508	7288	404
4·83	220	18·08	8936	495	7642	424
7·01	332	8·48	142	15	82	10
6·88	325	8·40	509	61	286	31
6·74	318	8·16	1820	224	1450	178
6·44	305	8·36	4570	545	3670	438
6·26	297	8·28	5470	657	4390	529
6·08	289	8·24	6060	733	4940	601
5·86	276	8·16	6710	825	5530	677
5·64	263	8·16	7120	870	5980	733
5·49	255	8·16	7470	916	6300	774
5·29	244	8·16	7530	921	6390	784
5·04	231	8·16	7850	962	6730	825
4·54	206	8·16	8100	993	7000	855
4·14	190	8·16	8020	982	7000	855
7·03	333	5·6	0	0	0	0
7·00	332	5·6	0	0	0	0
6·91	327	5·6	267	50	164	31
6·57	310	5·6	3300	614	2670	477
6·25	297	5·52	5040	911	4220	763
6·04	287	5·52	5620	1019	4780	865
5·78	271	5·52	6070	1100	5230	947
5·63	263	5·52	6310	1140	5500	993
5·49	255	5·52	6360	1150	5560	1000
5·33	246	5·52	6360	1150	5580	1010
5·16	237	5·52	6360	1150	5580	1010
5·04	231	5·52	6440	1170	5680	1030
4·64	211	5·52	6201	1130	5490	993

XX.—On Skulls of Horses from the Roman Fort at Newstead, near Melrose, with Observations on the Origin of Domestic Horses.

By J. C. Ewart, M.D., F.R.S., Regius Professor of Natural History, University of Edinburgh. (With Three Plates and Six Text-figures.)

(Read November 19, 1906. Issued separately May 9, 1907.)

Introductory.

Archæologists and students of Roman Scotland have long known that somewhere in the neighbourhood of Newstead, near Melrose, lay the site of a Roman settlement.

Excavations which have recently been undertaken by the Society of Antiquaries of Scotland, under the direction of Mr James Curle, F.S.A., of Priorwood, Melrose, have been successful in ascertaining, to the east of the village of Newstead, the exact position of a large fort, which occupied a commanding position within sight of the Eildon Hills.

During the excavations, in addition to a cavalry helmet, armour, wheels, bridle-bits, fragments of leather, and numerous articles of various kinds made use of by the Romans, a considerable number of bones of wild and domestic animals have been found, with the result that the fort at Newstead promises to prove almost as interesting to biologists as to antiquaries.

At the request of Mr Curle I visited the Newstead fort early in 1906, with a view to reporting on the collection of horse bones.

Hitherto when bones of horses have been met with during excavations, it has generally been deemed sufficient to record as accurately as possible the number of animals they represented, and to indicate at what level and under what conditions they were discovered. But now that the multiple origin of the domestic breeds of horses is considered probable, it occurred to me that a careful study of the bones from Newstead might shed fresh light on the origin of our modern breeds, as well as add to our knowledge of the Roman war-horse and of the small fleet horses the ancient Britons yoked to their war-chariots. I accordingly arranged for all horse bones unearthed at Newstead being sent to Edinburgh, and I now propose to submit to the Society the conclusions arrived at from a comparative study of the skulls.

For the following information as to the finding of the skulls, I am indebted to Mr Curle:—Thirteen horse skulls were found in pits outside the fort, two in a pit in the outer courtyard of the prætorium, and two others in a pit within the fort a little to the north of the east gate. In every case the skulls and other bones lay in a dark deposit having a peculiar odour, and crowded with twigs and small fragments of wood. Of the pits outside the fort, one (the Horse pit) which lies to the south of the defences was

31 feet 9 inches in depth, and varied in diameter from 6 feet 6 inches at the top to 4 feet 10 inches at the bottom. The upper portion of the pit was occupied by a thick layer of clay, then came the characteristic black deposit, the first eighteen feet of which contained nine skulls and many bones of horses. At 18 feet 9 inches, a human skeleton —that of a dwarf—occurred. Below this lay the skull of a dog, shells of oysters and mussels, fragments of leather and portions of a decorated Samian bowl with vertical sides, a small undecorated platter, and, at the very bottom, a heavy iron hammer.

A second pit, beyond the defences, contained three horse skulls. This (the Wheel pit) had a depth of 30 feet, with a diameter of 8 feet at the top and 10 feet at the bottom. At a depth of 18 feet 11 inches from the top of the black deposit, a fragment of a decorated Samian bowl with a figure of Pan was found. Two feet under this bowl were two horse skulls; two feet deeper, two wooden wheels, a human skull, and deer horns; at 23 feet, a third horse skull and the skulls of five dogs; and deeper still, an oak bucket.

The third pit in the field outside the fort had a depth of 23 feet, the diameter at the top being 8 feet 6 inches, at the bottom, 10 feet. This (the Armour pit) contained, about 8 feet from the surface, the greater part of a Samian bowl and pieces of amphoræ; at 10 feet, a horse skull; at 17 feet, a fine Andernach quern; and at 18 feet, three helmets, several inscribed pieces of armour, two bridle-bits, and a quantity of leather.

Of the two pits inside the fort, one (the Prætorium pit) had a depth of 25 feet 6 inches, and a diameter varying from 25 feet 6 inches at the surface to 6 feet 6 inches at the bottom. At 15 feet from the surface lay two horse skulls, and skulls of Bos longifrons, sheep, and red deer. This pit also contained, at 8 feet, a human skeleton; at 12 feet, an altar, underneath which lay a brass coin of Hadrian; at 22 feet were two human skulls (one incomplete), the bottom of a Samian dish, numerous brass armour-scales, portions of an iron lorica, two knives, a linch-pin, a quantity of leather, the remains of two oak buckets, and fragments of many amphoræ. At the bottom a brass coin was obtained belonging to the reign of either Vespasian or Titus.

The pit to the north of the east gate (the Gate pit) contained the remains of several horses. This pit was 17 feet deep, 8 feet 8 inches at the top, and 3 feet 10 inches at the bottom. The horse bones, together with bones of various other animals, occurred in the lower 10 feet. This pit also contained a small dish of thin, hard Samian ware with vertical sides, two spear-heads, a hook for a lamp, and the necks of several amphoræ.

Mr Curle thinks that at least some of the pits from which the skulls were obtained were disused wells—wells which, having become foul, were utilised for the deposit of rubbish and the carcases of dead animals. As to the age of the pits, it is believed that the Horse and Armour pits may be as early as the end of the first century—this is suggested by the portions of Samian bowls they contained—while the Wheel pit probably belongs to the second century. The pits within the fort, it is believed, cannot

be much if at all earlier than the middle of the second century. That the Prætorium pit belongs to the second century is suggested by the coin of Hadrian (117–138 A.D.), while the remaining pit is connected by a drain with a building which seems to belong to a later occupation of the fort.

From the above facts, kindly supplied by Mr CURLE, there seems no escape from the conclusion that the skulls which form the subject of this paper belonged to horses used for cavalry and other purposes by Roman auxiliaries, who, during the latter part of the first century, as well as during a considerable portion or portions of the second century, occupied the settlement now commonly spoken of as the Newstead Fort.

SIZE OF THE HORSES IN THE NEWSTEAD FORT.

In regard to the skulls, one of the first questions requiring an answer is—Of what sizes were the horses to which they severally belonged?

It has hitherto been assumed that in horses the height at the withers is two and a half times the length of the head. By making measurements of living horses I have, however, ascertained that the relation between the length of the head and the height at the withers is far from constant. This is in some cases due to the limbs being relatively very short, in others to the head or limbs being relatively very long.

Partly from skulls of horses of a known height, and partly by measuring living horses, I made out: (1) That in dwarf varieties (*e.g.* Shetland ponies, in which the limbs are relatively very short) the height at the withers may be only 2·3 times the length of the skull;* (2) that in the wild horse of the Gobi Desert (*Equus prejvalskii*), in which the head is relatively very long, the height at the withers is in some cases slightly less than 2·4 times the length of the skull; (3) that in ponies of the Celtic type, which have undergone little alteration either from dwarfing or domestication, the height is as a rule 2·5 times the length of the head; (4) that in well-bred Arabs the height is from 2·6 to 2·7 times the length of the head; and (5) that in broad-headed Highland ponies (*i.e.* in horses of the Forest type) the height at the withers may be slightly more than 2·7 times the length of the head.

I may here mention that mainly by studying the external characters, the vertebral column, and the limb bones, I, some years ago, arrived at the conclusion that domestic horses had sprung from several wild species. Recently I pointed out that three distinct varieties can still be identified, viz.: (1) The Steppe variety, represented by Prejvalsky's horse (Pl. III. fig. 11) of the Great Gobi Desert of Mongolia; (2) the Plateau variety, examples of which we have in the Celtic pony (Pl. III. fig. 8) of north-western Europe, and in a slender-limbed Mexican race (Pl. III. fig. 10—horse on right of figure); and

* The length of the skull is obtained by measuring from the occipital crest to the alveolar point, *i.e.* to the base of the wedge-like piece which projects between the upper-central incisors. In living animals, the length of the skull is arrived at by measuring from the summit of the ridge across the top of the head to the edge of the gum which projects between the central incisors, and deducting 4 mm. for the skin over the occipital crest and the mucous membrane covering the alveolar point.

(3) the Forest variety (Pl. III. fig. 9), specimens of which occur in Asia, but especially in the north of Europe.*

When I proceeded to make a comparative study of the skulls from the Newstead Roman camp, I was at once struck with the fact that they included three well-marked types; that, in other words, the Roman auxiliaries who garrisoned the Newstead fort had in their possession in addition to cross-bred animals, three very distinct varieties of horses, all of which possibly still existed in a wild state at the end of the first century. Further, owing doubtless to intercrossing having been less practised during the first century than during recent times, it was in most cases possible to say with some certainty from which of the three varieties the cross-bred animals had inherited their chief characteristics.

Of the three distinct kinds of skulls, one is characterised by a very narrow facial region, one by having a short, broad face, while the third has a very long face bent downwards so as to form a distinct angle with the cranium. These marked differences in the skulls from the Roman fort led me to re-examine the skulls of modern horses. The result of a comparative study of the skulls of living varieties with the skulls of the first and second centuries from Newstead, conclusively proved: (1) That the greatly bent long Newstead skulls are almost identical with the skull of *Equus prejvalskii* of the Great Gobi Desert—the only wild horse now living; (2) that the very narrow skulls agree in all essential points with the skulls of typical Celtic ponies and with the skulls of certain high-caste Arabs; and (3) that the broad-faced skulls with the face nearly in a line with the cranium closely resemble the skulls of horses of the Forest type frequently met with in the north of Europe and in the north and west of Asia. These facts established, I was in a position (1) to estimate the size of the horses in possession of the Gaulish and other auxiliaries who garrisoned the Newstead fort during the first and second centuries, and (2) to arrive at a fairly accurate conclusion as to the make, speed, and temperament of these horses, and thus settle to which modern types they are most intimately related. To determine the size of the Newstead horses, I selected for special study (1) two narrow skulls, one in which the total length (length of the vertex) was 494 mm., and one in which the length was 534 mm.; (2) a short-faced broad but nearly straight skull, measuring 547 mm.; (3) a skull with a very long bent face, measuring 560 mm.; and (4) the longest skull in the collection, in which the length of the vertex (*i.e.* from the occipital crest to the alveolar point) was 582 mm.

The small narrow (494 mm.) skull I found closely agreed with the skull of a Hebridean (Celtic) pony which, when three years old, measured 48 inches (12 hands) at the withers. In this pony the height was 2·5 times the length of the skull.

Assuming that the Newstead pony, with a 494 mm. skull, was built on the lines of the Celtic variety, it would probably measure, when alive, 48·6 inches, *i.e.* slightly over 12 hands.

* Ewart, "The Multiple Origin of Horses and Ponies," *Trans. Highland Soc. of Scotland*, 1904. "The Tarpan," etc., *Proc. Roy. Soc. Edin.*, 1906.

The 534 mm. skull closely resembles in its main features the skull of a typical Arab imported some years ago from India, which measured 55·5 inches. In this Arab the height at the withers was 2·7 times the length of the skull, from which it may be inferred that the Roman horse with an Arab-like skull measured, when alive, about 56·8 inches at the withers, *i.e.* over 14 hands.

The broad skull, 547 mm. in length, obviously belonged to the Forest type—the type to which belong many of the stout, short-necked, round-quartered, deer-stalking ponies of the Scottish Highlands. In typical Highland ponies, as in Arabs, the height is frequently 2·7 times the length of the skull. It may hence be assumed that the broad-faced Roman horse measured, in round numbers, 58 inches (14·2 hands) at the withers.

The 560 mm. skull obviously belonged to a horse of the Steppe type with, perhaps, a trace of Forest blood. To make allowance for this admixture I multiplied the 560 mm. skull by 2·5 instead of 2·4, which gives a height at the withers of 55 inches or 13·3 hands.

As the very long skull seemed to belong to a cross-bred animal of a long-limbed high-withered type, the length (582 mm.) was multiplied by 2·6, which gives a height of 59·5 inches or just under 15 hands at the withers.

Assuming that these measurements are fairly accurate, it follows that at, or about, the end of the first century the Roman auxiliaries stationed at Newstead had in their possession horses varying from 12 to 15 hands.

The Varieties of Horses in the Newstead Fort.

The height of the Newstead horses having been approximately fixed, the question arises—Does a careful examination of the skulls from Newstead support the view arrived at from a superficial examination, viz., that there were three perfectly distinct varieties of horses in this Roman fort in the south of Scotland about the end of the first century, and that representatives of these three varieties are still living? Never before, as far as I can learn, has there been a like opportunity for studying the horses of Europe during the first and second centuries, and seldom before when horse skulls were under consideration has the possibility of the multiple origin of domestic horses been taken into consideration.

A detailed study of the Newstead skulls implies making use of the methods of the anthropologist. For some years craniological measurements have played an ever-increasing part in the classification of mammals; but a method has not yet been devised, and is hardly likely ever to be devised, capable of being applied to all groups of mammals.

In studying a collection of skulls, the chief object in view is to find out in what respects they essentially agree with or differ from each other and from skulls of allied races or varieties.

By making too many measurements the differences are apt to be obscured;

and, it may be added, by comparing the measurements of skulls of different ages, and by taking the average of skulls belonging to different varieties, real and essential differences are almost inevitably lost sight of.

In the case of human skulls it is especially important to determine the cephalic index, *i.e.* the relation of the breadth to the length of the cranium, the length being taken as 100. But as, for various reasons, the skulls of horses differ from each other in the facial more than in the cranial portion, measurements of the face are in their case especially important.

About the horse, we especially want to know (1) what relation the width of the face bears (*a*) to its length, and (*b*) to the length of the base of the skull; (2) to what extent the face is bent downwards on the cranium; and (3) to what extent the outline of the face is modified by the development of frontal sinuses, and by an increase in the vertical extent of the nasal fossæ.

In the human skull there is no difficulty in deciding where the cranium ends and the face begins; but in the horse it is so difficult to say where the face begins that at least three ways have already been suggested for obtaining the length of the face, and I have found it necessary to introduce a fourth.

Czerski, to obtain the length of the face, measured from the central incisors to the anterior border of the orbit. Salensky,* recognising that the anterior border of the orbit does not coincide with the junction of the cranium and the face, measured from the central incisors to the point of union of the frontal and nasal bones, *i.e.* to the posterior end of the internasal suture. But as the end of the internasal suture does not at all coincide with the end of the cranial cavity, and as the line of the naso-frontal suture varies considerably—extending further along the face in some cases than in others—I decided to obtain the length of the face by measuring from the central incisors (the alveolar point) to a line connecting the posterior borders of the orbits. This line coincides almost exactly with the most anterior portion of the cranial cavity. The width of the face is best arrived at, as Nehring recognised, by measuring between the outer margins of the orbits. This (the frontal width) multiplied by 100 and divided by the facial length gives the frontal index.

The extent to which the face is bent downwards on the cranium is made evident when outlines of photographs of side views of skulls are placed one above the other, and when the angle formed by the line of the palate and the basi-cranial axis is given. The difference between a bent skull in which the frontal sinuses and the nasal fossæ are highly developed and a skull with a concave facial outline, is best indicated by adding to a photograph of a dish-faced skull the facial outline of a skull of the "Roman-nosed" type.

If, as seems probable, the remote three-toed ancestors of the Equidæ were adapted for a forest life, it may be assumed that the variety now most richly striped, and

* The methods of Czerski, Nehring, and others for measuring horse skulls are described in Salensky's work on Prejvalsky's horse. Translation by Hayes & Bradley. Hurst & Blackett, 1907.

otherwise adapted for living in the vicinity of forests, is more primitive than varieties specialised for a steppe or a plateau life.

Taking this for granted, I decided to study first a Newstead skull which seemed to belong to a horse of the Forest type, *i.e.* a skull with a short, broad face.

It has long been realised that in some ruminants the facial portion of the skull is nearly in the same line with that of the cranium, while in others the face is bent downwards so as to form a marked angle with the cranium. In the elk, *e.g.* when the skull is placed so that the basi-cranial axis is horizontal, the nose is directed forwards; while in the sheep, with the skull placed in the same position, the nose is directed downwards.*

To an expert in equine skeletons, the skulls from the Roman fort at Newstead which most closely approach the Forest type would probably not appear very remarkable: being neither very long nor very bent nor irregular in outline, they would probably be regarded as fairly typical skulls of what used to be termed the common horse. Nevertheless the Newstead skulls, with a short, broad, dished face, belong to a very distinct type. They are especially characterised by (1) the large frontal index; (2) the outline of the face being concave; (3) the face being, as in the elk, only slightly bent on the cranium; and (4) by the elevated position of the distal portion of the nasal bones. In the 547 mm. Newstead skull of the Forest type (Pl. I. fig. 1) the length of the face is 372 mm., the width 228 mm.—hence the frontal index is 61·29;† in the long-faced Steppe variety from Newstead the frontal index may be as low as 50, in *E. grevyi* it may be only 47. The frontal index is high in the Forest variety, because the face is broader and at the same time shorter than in the Steppe and Plateau varieties.

Quite as distinctive as the high frontal index is the outline of the face. From the highest point of the cranium to the summit of the eminence formed by the free distal portions of the nasals, the outline is concave (Pl. II. fig. 6). This "dished" condition of the face is partly due to the distal portions of the nasals being elevated, and partly to the absence of a prominence in the region of the frontal sinuses and over the proximal portions of the nasal fossæ.

In ungulates adapted for a forest life, *e.g.* the tapir and elk, the nasals are usually short and arched upwards apparently to add to the mobility of the upper lip. In like manner (though not nearly to the same extent) horses of the Forest variety are specialised, the nasals being both shorter and more arched upwards than in, for example, Prejvalsky's horse, a member of the Steppe variety.

In descriptions of the skull of the horse it is frequently stated that the basal line of the cranium, from the lower border of the foramen magnum to the incisor border of the palate, is very nearly straight.‡

* The difference in the relation of the face to the cranium in these two forms is perhaps accounted for by the fact that the elk is a short-necked Forest form adapted for feeding on shrubs and trees, *i.e.* for holding the head in a nearly horizontal position, while the sheep is a denizen of the mountains, adapted for holding the head when feeding in a nearly vertical position.

† For other indices, see Table I.

‡ Flower and Lydekker, *Mammals, Living and Extinct*, p. 389.

In some horse skulls a line between the foramen magnum and the incisor border touches the posterior border of the palatine bone, and the hard palate is nearly parallel with the basi-cranial axis. Even in such skulls the face is not exactly in line with the cranium, for when a line is carried through the basi-cranial axis it emerges a considerable distance above level of the incisors (Pl. II. fig. 6). In other horse skulls a line extending between the foramen magnum and the incisor border may be 25 mm. below the level of the posterior border of the palatine bones, and a line passing through the basi-cranial axis may emerge about midway between the posterior border of the orbit and the tips of the nasals (Pl. II. fig. 7); in such skulls the face is so bent downwards on the cranium that the hard palate forms a marked angle with the basi-cranial axis.* In three of the Newstead skulls, a line carried through the basi-cranial axis indicates that in some of the horses in the possession of the Romans or their auxiliaries the face was even less bent than in modern examples of the Forest variety. This is borne out when Pl. II. fig. 6 (a Newstead skull) is compared with Pl. I. fig. 2 (the skull of a modern Iceland pony of the Forest type).

In the Newstead skulls of the Forest type one also notices that the temporal ridges are well developed; that the orbits are nearly circular and surrounded by wide-rimmed margins; that there is a preorbital depression for the elevator muscle (*Levator labii proprius*) of the upper lip; that the occipital condyles are separated inferiorly by a wide groove (Pl. I. fig. 3); and that, as might be expected in a Forest form, the incisors project well forwards (Pl. I. fig. 1.) From the fact that the 547 mm. skull has a short, broad, concave face, it may be assumed that it belonged to a horse of the Forest variety,† *i.e.* to a stout horse with a heavy mane and tail, a short neck, very long body (with six lumbar vertebræ), round quarters, a low set-on tail, short strong legs, thick fetlock joints and broad hoofs—a horse built on the lines of the Highland ponies (Pl. III. fig. 9) used by deer-stalkers, and of the smaller kinds of long-bodied Flemish horses with a short, broad, dished face. Three skulls of this type have thus far been found at Newstead.

From the Roman skulls of the Forest type in which the face is only slightly bent downwards on the cranium, as in the elk, I shall pass to the Newstead skulls of the Steppe type, in which the face forms a well-marked angle with the cranium as in sheep and oxen, and in *E. Scotti* of the American Pleistocene.

* Professor LANKESTER, in his paper on the Okapi, points out that "the whole brain-case or post-orbital region of the skull of the Bovidæ appears to be bent down as on a joint across the junction of the cranial and facial portions of the skull"; and he adds, "there is good ground for connecting the presence of the deflection of the cranial cavity above noted with the mechanical conditions arising from the use of horns having the position and direction of those found in Bovidæ and the Giraffe" ("On Okapia," *Trans. Zool. Soc.*, vol. xvi. pt. 6). If, as Professor LANKESTER suggests, the deflection is connected with the use of horns, it should doubtless be regarded as due to the downward bending of the cranium on the face. If, on the other hand, the deflection is connected with grazing, with feeding on short herbage close to the ground, it might be more accurate to regard it as due to the bending downwards of the face on the cranium. There is no evidence that any of the ancestors of the Equidæ possessed horns, or that either in Prejvalsky's horse or the other recent Equidæ with a pronounced deflection is the forehead used for defence or attack. Moreover, in the Elk (*Alces*), notwithstanding the large horns, the face is nearly in a line with the cranium

† This view is supported by the 547 mm. Newstead skull agreeing in the frontal and other indices with the skull of an Iceland pony (Pl. I. fig. 2) of the Forest type; *e.g.* in the Newstead skull the frontal index is 61·29, and in the Iceland skull 61·30.

The best example of the bent type of skull from the Newstead fort is represented in Pl. II. fig. 7. The difference between a relatively straight skull of the Forest type and a skull of the Steppe type is most realised when two such skulls are so placed that the basi-cranial axis occupies a horizontal position. This difference is well brought out in Pl. II. figs. 6 and 7. In Pl. II. fig. 7, which represents a strongly bent Newstead skull, a line carried through the basi-cranial axis emerges between the upper and middle thirds of the nasals, whereas in a skull of the Forest type a similar line emerges well below the tips of the nasals (Pl. II. fig. 6). I may here mention that there are excellent reasons for believing that a bent skull greatly facilitates feeding on very short herbage. In a sheep, when feeding, the grass is pressed by the sharp-edged lower front teeth against the hard pad attached to the upper jaw; and then as a rule the head is jerked rapidly forwards, with the result that the grass, held as in a vice, is severed partly by cutting and partly by tearing.

In the Steppe variety of the horse the grass is seized between the upper and lower incisors, but the head, instead of being invariably jerked forwards—the usual procedure in sheep—is sometimes moved forwards, sometimes backwards, but more frequently from side to side.

It is especially interesting to note that, in members of the Forest variety, the face at birth is nearly as bent downwards on the cranium as in full-grown members of the Steppe variety. The reason of this may perhaps be that in the case of mammals which suck standing, the milk is obtained more readily when the face is bent downwards on the cranium. To induce the flow of milk the mammary gland requires to be pressed—at times with considerable force—and this pressure is apparently more readily effected when the face is bent downwards than when in a line with the cranium; the snout, it need hardly be said, in forms which suck standing, plays the part of the fore-limbs in forms which take their nourishment in a recumbent or sitting attitude. That the downward bending of the face at birth is connected with sucking seems to receive support from the fact that in the very young Giraffe the deflection of the cranium is as pronounced* as in full-grown sheep and goats. Though the deflection of the face on the cranium may facilitate sucking, it is extremely probable that it was originally acquired to facilitate grazing. During the first year, but more especially during the first four or five months, grazing is difficult, because while the legs are very long the neck is still extremely short. Even with the fore-legs wide apart it would be difficult for a foal to seize short grass with the face in a line with the cranium. That a face bent downwards as in sheep counts for something in the foal is suggested by the fact that the deflection is more marked in foals of mountain and moorland ponies than in foals of thoroughbreds—a race which has long lived under very artificial conditions.

From the fact that the face is bent downward at birth it might be assumed that

* The skull of a very young Giraffe is figured in Professor LANKESTER'S paper on the Okapi (*Trans. Zool. Soc.*, vol. xvi.). In the young Giraffe it certainly looks as if the cranium had been bent downwards on the face in the interest of the horns.

this is a primitive condition, and that the Forest variety in having the face, on reaching maturity, nearly in a line with the cranium, is more specialised than the Steppe horse in which the face is as strongly bent downwards in the adult as in the foal. If in the Steppe horse the bent condition present in the foal persisted up to adult life, some support would be given to this view; but when it is mentioned that in the Steppe horse, as the foal grows older, the face is gradually unbent, it will be evident that the Steppe variety is eventually the more highly specialised. Owing to the gradual unbending during the first year, the skull of a fifteen months Prejvalsky's horse (Pl. I. fig. 5) very closely resembles the skull of an adult Forest horse (Pl. I. fig. 2). But during the second year the face again begins to bend downwards in the Steppe horse, and the bending continues until it forms a well-marked angle with the cranium (fig. 1). If the

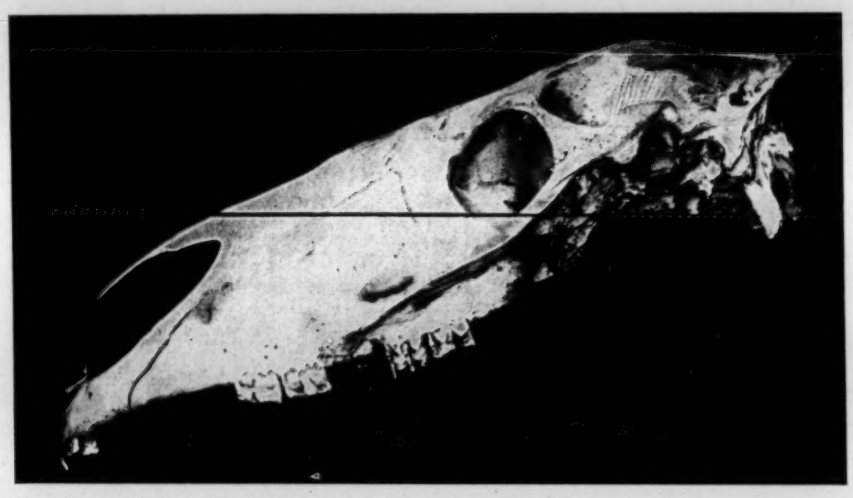


FIG. 1.—Lateral view of the skull of a Prejvalsky stallion (age about 3 years 8 months). The face is bent downwards on the cranium, and the post-orbital part of the skull, as in the deflected Roman skull (Pl. II. fig. 7), is relatively short. There is a slight prominence below the level of the orbits, such as often occurs in Shire horses, and the nasals are long and bent downwards at the tips. The outline of the face, instead of being concave as in the Forest horse, is convex; in some cases the curvature is more marked than in the skull figured, and the premaxillæ are longer and bent down on the maxillæ. The difference in the facial outline between old and young Steppe horses is due to an expansion of the frontal sinuses and to an increase in the depth of the nasal fossæ. The increase in the length of the orbit has probably resulted from the articular surfaces for the mandible having been shunted backwards. Skull of horse in fig. 12, Pl. III.

bending of the face on the cranium has, as seems probable, been effected very gradually (since forests and marshes were abandoned for a free life in open plains and uplands), it follows that the Steppe variety branched off from the common stem at a very remote period.* It is especially worthy of note that the Steppe horse, in having for a time a nearly straight skull, repeats during its growth one of the most striking characters of its remote forest-haunting ancestors.

The deflected Newstead skulls also differ from skulls of the Forest type in the outline of the face. Between the highest point of the cranium and the most elevated part of the nasal bones, the outline is always concave in the Forest variety, *i.e.* in the Forest variety the face is dished (Pl. I. fig. 2). In a yearling Steppe horse the outline

* In *Neohipparion* of the Miocene, *Hipparion* of the Pliocene, and *E. Scotti* of the Pleistocene, the face is strongly bent downwards on the cranium.

of the face is also concave (Pl. I. fig. 5), but in the adult it is always decidedly convex (Pl. II. fig. 7). This change, from a dished face to a "Roman-nosed" condition, results in part from the bending of the face on the cranium, and in part from the expansion of the frontal sinuses and the vertical increase of the nasal fossæ.

The difference in the outline of the skull between a Forest and a Steppe horse is best realised by superimposing the outline of a "Roman-nosed" Prejvalsky horse on the skull of a dish-faced horse of the Forest type. This, however, somewhat exaggerates the difference between the facial outlines, because in the Steppe horse the face forms a more marked angle with the cranium. In fig. 1 it is impossible to say where the prominence due to the frontal sinuses ends and the elevation of the nasals begins; but in some cases either the frontal sinuses or the nasal fossæ are unusually developed, with the result that instead of an even contour there is a marked prominence either above or below the level of the orbits; in other cases both frontal sinuses and nasal fossæ are unusually large, with the result that there are two distinct prominences which give an extremely sinuous facial outline.

Prominent frontal sinuses and large upward extensions of the nasal fossæ have only been observed in horse skulls of the Steppe type, *i.e.* in skulls in which the face is very long and bent downwards. In the Kiang—a form which occurs up to a height of 15,000 feet—the nasal fossæ are also very extensive. It is hence possible that the great size of the nasal chambers is a special adaptation for a life in cold, mountainous areas. In horses living in cold regions, the moisture is in great part removed from the air by coming into contact with short, stiff hairs which stretch across the narrow nostrils; the air having got rid of some of its moisture at the nostrils, the large nasal fossæ may admit of its temperature being somewhat raised before it passes on to the lungs.

The Newstead skull (Pl. II. fig. 7) of the Steppe type not only differs from the skull of the Forest type (Pl. II. fig. 6) in having the face bent, it also differs in the cephalic and frontal indices. In length the cranium is 165 mm., in width 96 mm.—*i.e.* though in its total length 13 mm. longer, the cranium is 11 mm. narrower than in the skull of the Forest type (Table I.). In the latter the cephalic index is 67·29, in the Steppe-like skull it is only 58·18. Moreover, the two crania differ in shape; in the one (the Steppe skull) the sides of the cranium are flattened, whereas in the Forest skull the sides of the cranium are rounded and prominent.*

Compared with the Forest skull the 560 mm. Steppe skull has a very long face—it measures 399 mm. (26 mm. longer than the face in the Forest skull) by 223 mm., the frontal index being 50·33, or 10·96 less than in the Forest skull. The great length of the face has partly resulted from a backward shunting of the articular surfaces for the mandibular condyles. One result of this shunting is a diminution of the post-orbital

* The cranium of the skull represented in Pl. II. fig. 7, is probably abnormally small; perhaps small-brained members of the Steppe variety were more easily domesticated than individuals with a large brain, such as normally occurs in the recent Steppe horse, *E. prejvalskii*.

part of the skull; another has been the lengthening of the mandible, doubtless that it may more effectively deal with hard dry food during winter.

Of the Newstead skull of the Steppe type it need only be mentioned further: (1) That the occipital condyles, separated by a very narrow groove, are so placed that the head readily assumes a nearly vertical position; (2) that the premaxillæ are long, narrow, and strongly bent downwards; (3) that the first premolar (wolf) teeth are large and functional, while the second, third, and fourth premolars, as well as the three molars, are smaller than in the Forest variety from Newstead. It has already been mentioned that though the 560 mm. Newstead skull (Pl. II. fig. 7) belonged to a horse about fifteen years of age, it, as I anticipated, very closely agrees with the skull (fig. 1) of a four-year-old Prejvalsky horse imported from Mongolia.

They agree in the cephalic index (58·18 in the Newstead skull and 60·00 in the Prejvalsky skull), and differ but little in the frontal index: for notwithstanding the undeveloped state of the young Prejvalsky horse, the frontal index is only 50·94; in the Newstead skull of the Prejvalsky type it is 50·33. The bending of the face on the cranium is not so pronounced in the three-year-old wild horse; but when it is remembered that in a fifteen months' Prejvalsky horse the skull is nearly as straight as it is in an adult Forest horse, the less bent condition of the face in the three-year-old Steppe horse is at once accounted for. A consideration of the 560 mm. Newstead skull may hence be said to point to the conclusion that it belonged to a horse very closely resembling in make, and presumably also in temperament, Prejvalsky's horse (Pl. III. fig. 11): a form still living in a wild state in the vicinity of the Great Altai Mountains, specimens of which, through the instrumentality of His Grace the Duke of Bedford, were some years ago imported into England.

In addition to the 560 mm. skull, there are two others from Newstead which belong to the Steppe or Prejvalsky variety, *i.e.* to a variety characterised by a long face (Pl. III. fig. 12), convex in outline and bent downwards on the cranium, a short neck, a short back, and only five lumbar vertebræ—in the Forest variety there are six—a straight croup and a high set-on tail, slender limbs, long metapodial bones, small fetlock joints and narrow hoofs, an upright mane and a remarkable mule-like tail; to a variety having a wonderful facility for clearing obstacles, and characterised by an indomitable temper.

We now come to the Newstead skulls of the Plateau type. One of these, which closely agrees in size and outline with that of a 12-hands Celtic pony, is alike remarkable for the narrowness of the face and the width of the cranium. Although this skull is 65 mm. shorter than the skull of the Steppe type last considered, the cranium is 12 mm. wider; and though 88 mm. shorter, it is as wide as in the longest skull from Newstead.

The cranium, 156 mm in length, has a width of 108 mm., which gives an index of 69·23, *i.e.* 11·05 higher than in the 560 mm. Newstead skull of the Steppe type. The frontal index of the small Newstead skull is 54·11—nearly intermediate between the Newstead skulls of the Forest and Steppe types, which are respectively 61·29 and

50·33, but less than in a fairly typical Celtic pony from the Hebrides, in which the frontal index is 57·65. This intermediate condition mainly results from the fact that while in the small Newstead skull the face is practically twice the length of the cranium, in the Forest skull it is 1·9 and in the Steppe skull 2·4 times the length of the cranium. Were the face of the small Newstead skull relatively as long as in the 560 mm. skull of the Steppe type, the frontal index would only be 46·25, *i.e.* 15·04 less than in the Newstead skull of the Forest type. It may be remembered that though the face of the narrow Newstead skull of the Celtic type is relatively decidedly shorter than in the Newstead horse of the Steppe type, it is relatively longer than the Newstead skull of the Forest type. Evidence of this we have when the length of the face is multiplied by 100 and divided by the cranio-facial length (distance from upper border of foramen magnum to alveolar point). In the Newstead Steppe horse the index is 75·52, in the horse of the Celtic type 72·03, in the horse of the Forest type (owing to the face being relatively shorter than in the others) it is 69·63.

In the small Newstead skull of the Celtic type the face is more bent downwards than in the Newstead skull of the Forest type. A line carried through the basi-cranial axis of a skull belonging to the Forest variety lies considerably below the tips of the nasal bones (Pl. II. fig. 6), whereas a similar line in the small narrow Newstead skull of the Celtic type lies slightly above the tips of the nasal bones. In the 495 mm. Roman skull, as in typical Celtic ponies, the outline of the face is concave, but, owing to the distal portions of the nasals being less arched, the dishing is less pronounced.

One further observes in the small Newstead skull that the orbits are relatively longer and less circular than in a Forest skull; that the nasals and premaxillæ are narrower; that the occipital condyles, as in the Forest variety, are separated by a wide groove (in the Steppe type the condyles are almost in contact); and that the articular surfaces for the condyles of the mandible, instead of lying at right angles to the main axis of the skull, have their outer ends slightly inclined forwards. Further, the hard palate is relatively shorter than in either Steppe or Forest varieties.

Of three small skulls of the Plateau type found at the Newstead fort, two in all probability belonged to the Celtic variety (Pl. III. fig. 8), while the third belonged to a Celtic pony with a trace of Forest blood. It may hence be assumed that two of them were characterised by a small narrow face, a short strong back (with only 23 dorso-lumbar vertebræ), and well-formed hind-quarters; by having the tail in line with the croup but set on lower than in the Steppe horse; the limbs constructed for speed, with small joints, long fetlocks, and rounded hoofs; by having a very full mane and tail, the tail during winter being provided with a tail-lock; and by possessing only two of the eight callosities found in Forest and Steppe horses—the hind chestnuts as well as the four ergots being entirely absent.

In addition to small narrow skulls of the Celtic type, Newstead has yielded four long narrow skulls which may very well have belonged to Arab-like steeds measuring from 13·3 to 14·1 hands at the withers. One of these, 534 mm. in length, agrees very

closely except in its cranium with the 494 mm. small narrow Newstead skull of the Celtic type. In this skull the face is 372 mm. long and 203 mm. wide, the frontal index being 54·04, *i.e.* only ·7 less than in the small skull of the Celtic type. Not only is the frontal index similar: the face bears the same relation to the base of the skull. The length of the face (372 mm.) multiplied by 100 and divided by the cranio-facial length, gives an index of 71·45; in the skull of the Celtic type it is 72·03. The narrowness of the face in the Celtic type is well brought out by comparing the 534 mm. skull with a skull of the Forest type in which the face happens to be the same length. In the one case the frontal width is 203 mm.; in the other (the Forest) the frontal width is 228 mm., nearly one inch wider.

The cranium of the 534 Arab-like Newstead skull is in length identical with the cranium of the 494 mm. skull of the Celtic type, but it is 5 mm. narrower; hence the cephalic index is less—66·02 against 69·32.

In the outline of the face and the amount of bending on the cranium, in the size and shape of the orbits, the width of the nasals, the width between the occipital condyles, the direction of the occipital condyles and the articular surfaces for the mandible and in the teeth,—the long Arab-like Newstead skull and the short Celtic-like Newstead skull are almost identical. From the close resemblance between the short and long narrow skulls, it may be safely assumed that they belonged to the same or to closely related races, *i.e.* were members of the Plateau variety. This view is confirmed by the fact that the 535 mm. Roman skull is in its measurements—in its total length, width and length of face—and in the relation of the face to the cranium almost identical with the skull of an Arab mare (Jerboa by Maidan out of Jerud) in the British Museum, and practically identical with the skull of a typical Mexican Plateau horse.

In addition to the 535 mm. narrow skull, there are three others from Newstead Arab-like in outline. One of these, though 10 mm. shorter, closely agrees with the one described; the other two, while agreeing in the main points, differ slightly, probably because they belonged to horses having a trace of Forest blood.

Whence came the Horses in the Newstead Fort?

The principal varieties of horses represented by the skulls from the Newstead fort having been enumerated, and their affinities with living varieties discussed, the question may now be asked—Whence came the horses in the possession of the Roman auxiliaries stationed in the south of Scotland during the first and second centuries?

It will be best to consider first whence came the three small horses which probably only measured from 48 to 50 inches at the withers. Professor Ridgeway of Cambridge, in his work on the Thoroughbred Horse, states that "the horse was everywhere driven under chariots before he was ridden." *

Why the horse was first driven is made sufficiently obvious by Herodotus in a

* Ridgeway, *Origin and Influence of the Thoroughbred Horse*, p. 423.

passage referring to the Sigynnæ, one of a number of tribes occupying Central Europe during the fifth century B.C. Of this tribe HERODOTUS writes: "They have horses with shaggy hair five fingers long all over their bodies. These horses are small and flat-nosed and incapable of carrying men, but when yoked under a chariot are very swift, in consequence of which the natives drive in chariots."

From the fifth century B.C. to the present day, horses in certain outlying parts of Europe have, from a military point of view, continued to be too small to ride; but during the second century B.C., according to RIDGEWAY, horses of a riding type able to carry men began to be imported from the south of Europe into Gaul, and from Gaul they were eventually introduced into Britain.

If the Sigynnæ and other tribes of Central and North-Western Europe used chariots because their horses, if not too small to ride, were at least too small to carry men into battle, it may be assumed that when larger horses became available the war-chariots would gradually disappear.

This is apparently very much what happened. The Gauls by the middle of the second century B.C. "had procured from Southern Europe horses of a size far superior to their own and better adapted for riding." * In fact, on the Continent, cavalry soon took the place of war-chariots, for ere Cæsar's time the chief strength of the Celtic and other inhabitants of Gaul lay in their horsemen.

But while on the Continent the war-chariot had been superseded by cavalry, it continued to be used in Britain for some time after Cæsar's day. When Cæsar reached Britain his advance was opposed by both cavalry and war-chariots; but the Belgic tribes of Britain, having few mounted men, trusted almost entirely to their charioteers.

From CÆSAR we learn that the small horses yoked to the British war-chariots were so active and well trained that they could be checked and turned in a narrow space, or pulled up when at full speed on a steep declivity, or made to stand while the charioteers ran out on the pole and stood on the yoke.

Though before Cæsar's invasion the Belgic tribes of the south of Britain had obtained from their kinsmen in Gaul a number of horses large enough to carry men, it seems that the tribes of Northern Britain had only small horses up to at least the beginning of the third century.†

TACITUS, in relating the doings of his father-in-law Agricola, refers to the war-chariots of the Northern Britons, but says nothing of British cavalry; and later still DIO CASSIUS states that the Caledonians and Mæatæ (the two chief tribes of Northern Britain) went to war in chariots, as their horses were small and fleet.

Since the country which these tribes inhabited would have been more easily traversed by men on horseback than by wheeled vehicles, we may assume with RIDGEWAY that the Caledonians used chariots because, during the second century, their horses were

* RIDGEWAY, *Origin and Influence of the Thoroughbred Horse*, p. 95.

† TACITUS mentions that at the battle of Mons Graupius the horse of one of Agricola's officers became unmanageable and carried its rider into the British lines. In such ways, and by capture, a few foreign horses would fall into the hands of the Caledonian and other tribes of Northern Britain.

still too small to carry men. As to the small fleet horses of the Northern Britons, RIDGEWAY says we may not unreasonably infer that they were ponies of the Celtic type, probably more or less mixed with the large-headed *Equus caballus* of Europe and Asia.

The horses on the Continent had been so increased in size and otherwise altered (mainly by the importation of improved breeds from the south of Europe) before the middle of the second century, that small 12-hands ponies were probably no longer easily obtainable along the routes traversed by the Roman legions and their auxiliaries. It may hence, I think, be assumed that the three small Newstead skulls belong to British ponies. Whether these ponies accompanied the Romans across the border, or were captured from one of the northern tribes, it is of course impossible to say.

It will be remembered that in one of the pits a pair of wheels was found. In these wheels the rim, instead of being made up of several felloes, consisted of a single piece of wood bent, as was the case with the wheel found in 1905 at Barhill as well as with that found in 1882 at La Tène in Switzerland. These wheels, according to those best able to judge, must be regarded as British until they are proved to be Roman. It is hence possible that the horses to which the small Newstead skulls belonged were captured along with a British war-chariot.

It was mentioned that two of the small skulls were practically identical, except in size, with the Arab-like skulls from Newstead.* This implies that they belonged to the same variety as the horses found in Switzerland on sites occupied during the La Tène period, *i.e.* during the later Iron Age. According to Dr MAREK, the Helveto-Gallic horses of the La Tène period were $13\frac{1}{2}$ to 14 hands at the withers—this seems to me a very high estimate—and in their fundamental characters agreed with Arabs.

It has been mentioned above that one of the small Newstead skulls seemed to belong to a pony having a trace of Forest blood. RIDGEWAY, it will be remembered, thought that some of the horses of the ancient Britons were probably mixed with the large-headed *Equus caballus* of Europe and Asia, *i.e.* with a horse of the Prejvalsky or Steppe type. I have failed to find any evidence of the existence in Britain, during the Roman period, of long-headed native horses with the face bent on the cranium. In Norway until quite recently the horses—with a few possible exceptions—seem either to have been Celtic ponies pure and simple, or a blend of the Celtic and Forest varieties.

Even now the fjord horse of Norway is largely Celtic, and, unless crossed with the heavy Gudbrandsdal race—a breed of Danish extraction,—there is no evidence of Steppe blood. Further, when we turn to Iceland, horses of the Steppe type are as a rule conspicuous by their absence. I recently inspected three hundred Iceland ponies; of these, under 10 per cent. had a trace of Steppe blood, and over 90 per cent. were either nearly pure Celtic or Forest horses or were crosses of these varieties. If, as seems highly probable, a certain number of Irish "Roman-nosed" horses—*i.e.* horses of

* One of several skulls from Walthamstow, Essex—probably of Neolithic age—in the British Museum, closely agrees in its measurements with the 495 mm. Newstead Celtic skull, while a second Walthamstow skull agrees with the small Newstead skull which seems to have belonged to a Celtic pony with a strain of Forest blood. Even in Neolithic times intercrossing seems to have been practised, or at least possible.

the Steppe type—reached Iceland through the Hebrides during the ninth and tenth centuries, one can understand why a small percentage of the modern horses of Iceland have a more or less distinct trace of the large-headed Steppe variety.

If the three small Newstead skulls belonged to native British ponies, they afford further evidence in support of the view that the small active British horses which attracted the attention of CÆSAR were either Celtic ponies pure and simple or a blend of the Celtic and Forest varieties; and being, except in size, almost identical with the finer kinds of Arabs, they help us to realise more fully the make of the horses that occurred in Switzerland during the La Tène period, and of the small, fleet, flat-nosed horses the Sigynnæ of Central Europe drove in their war-chariots during the fifth century B.C. Further support of the view that the small horses in the Roman fort at Newstead were British is afforded by the study of the bones of the limbs. More can usually be learned as to the variety to which any given horse belongs from the metacarpals or metatarsals than from the teeth. In the Forest type the length of the metacarpal is from 5·25 to 5·75 times the width at the centre of the shaft, whereas in the Steppe and Plateau types the length is from 7·25 to 7·75 times the width. The smallest metacarpals from Newstead are in length 7·5 times the width. The smallest Newstead metacarpals very closely agree with the metacarpals of Hebridean and Iceland ponies of the Celtic type and with metacarpals from the Romano-British town of Silchester. In the Forest type the metatarsals are in length from 6·6 to 7·2 times the width of the shaft, while in the Plateau type they may be over nine times the width of the shaft. In a metatarsal (British Museum) of Neolithic age from Walthamstow, Essex, the shaft is in length 8·8 times the width. In a Newstead metatarsal the length is 9·5 times the width of the shaft. It may hence be assumed that the small horses in the Newstead fort closely resembled horses which lived in Essex during Neolithic times.

If DIO CASSIUS and other writers are accurate in their accounts of the horses of the Caledonian and other Northern tribes, the large skulls from Newstead must belong either to horses that had been imported from the Continent or to large breeds that had been recently established in South Britain.

Assuming that the larger varieties had been imported, after full consideration I arrived at the conclusion that the long-headed horses of the Steppe type had come from either Germany or Spain; that the broad-headed horses of the Forest type had in all probability come from the Low Countries; that the narrow-headed horses of the Arab type might have come from Spain or the south of France, and that the majority of the cross-bred animals had come from the north of France.

That the coarse-headed horses in Newstead during the first and second centuries (A.D.) came from Germany, is suggested by CÆSAR's saying that "foreign horses in which the Gauls take special delight, and for which they pay large sums, the Germans do not employ; but their own native horses which are bad and ugly, they train to endure the severest toil by daily exercise."

Pure bred members of the Forest and Celtic varieties are neither bad nor ugly. The great width between the eyes makes the Forest horse look extremely sagacious, while the large eyes, well-placed ears, and narrow muzzle make the Celtic pony look refined and intelligent.

Of the Steppe horse, on the other hand, it is difficult to find words to sufficiently express the ugliness of the long, heavy, badly put-on head, or to describe the ingenuity wild specimens display in resisting attempts made to interfere with their freedom.

Believing that some light might be thrown on the origin of the Newstead horses by ascertaining from whence came the auxiliaries that garrisoned the forts on the northern frontier of Britain, I turned to Mr GEORGE MACDONALD, LL.D., of the Scottish Education Department, who has made a special study of some of the questions connected with the presence of the Romans in Scotland.

From the information which Mr MACDONALD has kindly placed at my disposal, it appears that there was at one time a 'German' regiment* at Birrens in Dumfriesshire (*cohors I. Nervana Germanorum miliaria equitata—i.e.* an infantry regiment 1000 strong with about every fourth man mounted). This regiment—which seems to have been moved to Birrens from Burgh-upon-Sands in Cumberland—being originally raised in Germany, may very well have contained many horses of the "bad, ugly" type mentioned by CÆSAR.

While the purer bred Steppe horses from Newstead may be of German origin, some of the cross-bred ones, in which the face is less bent and the profile less arched, may be Spanish. The foundation stock in Spain seems to have consisted to a very considerable extent of large-headed "Roman-nosed" horses. In all the countries which traded with Spain or were under her domination during the Middle Ages, "Roman-nosed" horses are more or less common. There is, *e.g.*, an Austrian breed of Roman-nosed horses originally imported from Spain; and horses with a marked convex profile are common in Ireland, and they are especially *en evidence* in Mexico and South America. It may hence be assumed that the 'Spanish' auxiliaries in Britain would include amongst their horses a considerable number allied to the "Roman-nosed" or Steppe variety. Though Newstead may never have been garrisoned by 'Spanish' auxiliaries, there was in 221 A.D. a 'Spanish' cavalry regiment (nominally consisting of 500 men) near Newcastle, while another lay long at Chesters on the North Tyne; and there were 'Spanish' infantry regiments including many horsemen (*cohortes equitatæ*) at Netherby north of Carlisle, at Ellenborough close to the west end of Hadrian's Wall, and at High Rochester in Northumberland north of the Wall. The gravestone of a soldier of a 'Spanish' *cohors equitata* has been found at Ardoch in Perthshire. With so many

* Mr MACDONALD points out that too much stress must not be laid on the territorial names of the auxiliary regiments; these names undoubtedly indicate the districts in which the regiments were originally raised, but there was no organised system of territorial recruiting, and consequently (as the inscriptions show) the soldiers were often of different nationalities. This need not vitiate the inferences which I suggest; the name of the district in which a cavalry regiment was originally raised is probably a safe index to the foundation stock of its horses.

'Spanish' regiments within easy reach, Spanish horses of various kinds may well have found their way to the important frontier fort at Newstead.

For centuries the Low Countries have produced horses of the Forest type—long, low, stout animals with a short broad head, short neck, round quarters, and a superabundance of forelock, mane, and tail; horses with thick legs, broad hoofs—resembling the figures on old Dutch plaques and "the Jumping Horse" of VELASQUEZ. During the second century there was a partially mounted regiment originally raised among the Tungri on the lower Rhine (*cohors II. Tungrorum miliaria equitata*) at Birrens in Dumfriesshire, while a regiment of cavalry (*ala I. Tungrorum*) from the same area has left inscriptions at Burgh-upon-Sands and also at Mumerills near Falkirk. Further, there was a partially mounted regiment of Vangiones (*cohors I. Vangionum miliaria equitata*) who also dwelt about the lower parts of the Rhine, stationed for a time at Risingham on the line between Newstead and Hadrian's Wall. All of these regiments probably contained a large proportion of horses of the Forest type, such as are suggested by some of the Newstead skulls.

As the Gauls from the second century B.C. onwards had been importing horses from the south of Europe, it seemed to me probable that the better bred horses in the Newstead fort came from Gaul.

I assumed that at least some of the better bred Newstead horses came from France, because CÆSAR points out that the Gauls took special delight in foreign horses for which they paid large sums. If the Gauls had well-bred horses, there is ready to hand a tempting explanation of the existence of Arab-like steeds in the Newstead fort; for Newstead was garrisoned, or at least partly garrisoned for a time, by a regiment of 'Gaulish' cavalry. This regiment (*ala Augusta Vocontiorum*) was originally raised among the Vocontii, *i.e.* in the district between the Rhone and the Alps,—a district which had doubtless long benefited by the importation of well-bred horses from the South.

In addition to the 'Gaulish' cavalry stationed at Newstead, there were several *cohortes equitatæ* from Gaul in garrison not very far from Newstead. One of these (*cohors IIII. Gallorum equitata*), which seems to have been moved to Britain from Spain, was for a time stationed at Risingham (on the direct line between Hadrian's Wall and Newstead) and at Castlehill, at the western end of the Scottish Wall.

With a cavalry regiment originally raised between the Rhone and the Alps in Newstead and with *alæ* or *cohortes equitatæ* or both from other parts of Gaul, as well as from Spain, Germany, and the Low Countries in garrison near the Scottish borders, it is not difficult to account for horses of very different types having occurred at Newstead, one of the largest, if not actually the largest Roman fort on the British frontier.

Do the Skulls from Newstead shed any light on the Origin of Domestic Horses?

Having described the skulls from the Newstead fort, we are now in a position to ask—What light do they throw on the origin of domestic horses?

Hitherto, for want of material—in the absence of crosses between typical members of the Forest, Steppe, and Plateau varieties; of skeletons belonging to the Palæolithic period, and especially of skeletons of typical representatives of modern varieties and breeds—it has been well-nigh impossible to arrive at general conclusions as to the origin of domestic breeds. Recently an important step has been taken by the Director of the Natural History Section of the British Museum towards providing material (skeletons, stuffed specimens, models, etc.) for a study of the origin and history of domestic animals. If a sufficient response is made by breeders and others to the appeal from the British Museum, a unique and extremely valuable collection will in course of time be formed—a collection which will assist greatly in solving problems of vital importance to stockbreeders. Although the skulls and other bones from the Newstead fort, together with the specimens in the British Museum, will not admit of dogmatic statements being made, they will at least make it possible to indicate from which varieties some of the more important domestic breeds of horses have inherited their more striking characteristics.

Though Hamilton Smith, some sixty years ago, argued in support of the view that domestic horses had sprung from several wild species, the single origin theory has hitherto almost universally prevailed.

Since 1902, I have on several occasions maintained that three or more wild species have taken part in forming the domestic breeds. A similar view has been promulgated by Professor Ridgeway in his work on *The Origin and Influence of the Thoroughbred Horse.*

Recently Professor Osborn, of the American Museum of Natural History, arrived at the conclusion that for untold ages there had been living contemporaneously several perfectly distinct kinds of wild horses adapted for different environments—some large, some small; some with broad hoofs adapted for a forest life, some with slender limbs and narrow hoofs adapted for a free life on boundless plains. Professor Salensky in his work on Prejvalsky's horse, published in 1902, asks: "In what genetic relationship does Prejvalsky's horse stand to the domestic horse? Has it given origin to any of the ancestors of the domestic? Had it in the past a wider geographical distribution than it has to-day?" In reply he says: "These questions cannot be answered definitely, for at the present time we have only very little actual foundation upon which to base the answer." In an addendum he adds: "The resemblance of *E. prejvalskii* to any of the varieties of the domestic horse is still open to question, since the material for making such a comparison by which alone the question could be settled is yet

insufficient in amount." Professor NOACK, on the other hand, thought it had been "irrefutably proved" that Prejvalsky's horse had an affinity to the pony.*

Professor RIDGEWAY, after passing in review all the chief breeds of horses, came to the following amongst other conclusions, viz.: (1) That there was a coarse, large-headed, indigenous, thick-set horse of a dun or white colour in Upper Europe and Upper Asia (probably derived from the same stock as Prejvalsky's horse), which continually moved southwards to the regions beyond the great mountain chains extending across the Asia-European Continent; and (2) that by the blending in varying degrees of these coarse dun and white horses with a Libyan variety of a bay colour evolved in North Africa, all the improved breeds of the world had been produced. In addition to the coarse large-headed horse of Europe and Asia, and the well-bred horse of North Africa, RIDGEWAY recognised the existence in North-West Europe of the Celtic pony; but as this pony is not credited with taking part in forming any of the improved breeds, RIDGEWAY may be said to derive domestic horses (with the possible exception of some of the ponies of North-West Europe) from two species or varieties, viz.—from (1) *Equus caballus*, the coarse large-headed horse of Upper Europe and Upper Asia closely allied to *E. prejvalskii*; and (2) *E. caballus libycus* of North Africa.

The skulls from Newstead clearly demonstrate the existence during the first century A.D. of three quite distinct kinds of horses, viz.: (1) A horse with the face long and arched, and strongly bent downward on the cranium; (2) a horse with a short, broad, dished face nearly in a line with the cranium; and (3) a horse with a narrow, dished face nearly in a line with the cranium.

The first, which in its head agrees with RIDGEWAY's large-headed horse of Upper Europe and Upper Asia, belongs to what I have termed the Steppe variety, and has either sprung from or is closely allied to Prejvalsky's horse.†

The second, not mentioned by RIDGEWAY, belongs to what some years ago I described as the Norse variety, but subsequently named the Forest variety. The majority of the horses with which LINNÆUS was familiar were doubtless fairly typical members of the Forest variety.‡

The third, which I have spoken of as the Plateau variety,§ includes two races, viz. the Celtic, adapted for a subarctic habitat, and the Libyan, adapted for a subtropical habitat. These races agree in all essential points with RIDGEWAY's Libyan variety.

* A similar view is held by Mr LYDEKKER, *Knowledge*, Aug. 1904.

† In the Steppe variety the face is very long (Pl. III. fig. 12), decidedly convex, and strongly bent on the cranium; there are only five lumbar vertebræ, the limbs are long and slender, the fetlock joints small, and the hoofs long and narrow. The mane is short and upright (hence there is no forelock), while the tail is mule-like. The dorsal band is narrow, and at the most only faint vestiges of stripes occur on the trunk and legs.

‡ In having the face nearly in a line with the cranium, a concave profile, six lumbar vertebræ, large fetlock joints and broad hoofs, a full mane and tail, a broad dorsal stripe, and stripes on the face, trunk, and legs, it profoundly differs from the Steppe variety.

§ In the Plateau variety the face is dished, as in the Forest variety, but longer, and slightly more bent. In colour and markings and in the number of the dorso-lumbar vertebræ, it agrees with the Steppe variety. From the Steppe as well as the Forest variety it differs in having a very narrow face, and in being devoid of hind chestnuts and all four ergots. Though in the Plateau, the hoofs are broader than in the Steppe, variety, the fetlock joints are as small and the "bone" as flat.

In 1902, as SALENSKY pointed out, it was impossible to say how Prejvalsky's horse was related to the domestic horse, or even to say that (notwithstanding NOACK's statement) it profoundly differed from the vast majority of ponies.

But now, thanks largely to the enquiries suggested by a study of the Newstead skulls, it is possible to indicate to what extent the Steppe variety (to which Prejvalsky's horse belongs) and also the Forest and Plateau varieties have contributed to the making of at least some of the domestic breeds.

It may now be asserted without fear of contradiction that all horses, whatever the breed, in which the face is long and decidedly bent downwards on the cranium, have in part sprung from ancestors allied to, if not identical with, the ancestors of Prejvalsky's horse. Though admitting this, it might be said that it is impossible to estimate the amount of the bending of the face on the cranium in living animals. This is doubtless true, but a fairly accurate index of the relation of the face to the cranium is afforded by its length and outline. If from well above the eyes down to near the muzzle the profile is distinctly convex, it may be safely assumed that the face is strongly bent on the cranium. When there is a marked prominence between and for some distance above and below the eyes, the face is also certain to be bent downwards, even although it tapers rapidly and is slightly concave about midway between the eyes and the nostrils.

Further, when the eyes appear to be near the ears, and the distance from the eyes to the nostrils seems excessive, the face is certain to be more bent than in horses of the Forest and Celtic type.

I have found the face decidedly bent downwards on the cranium in skulls belonging to the following breeds, viz. :—the Shire, Clydesdale, Hackney, Kattiawar, and Dongola, and also in skulls of several Arabs, Barbs, and Irish hunters, and in the skull of a Sulu pony.

In Shire horses the skull is sometimes nearly as bent as in the Newstead skull (Pl. II. fig. 7) of the Steppe type, and it is frequently more prominent below the level of the eyes. In the skull of a cart-horse represented in fig. 2, the frontal index is 52·60, the cephalic index is 61·30, and the cranio-facial index is 75·02.* Judging by the frontal index, the Steppe variety seems to have contributed three parts and the Forest variety one part to the making of this skull. Evidence of the Forest influence we have in the occipital crest being higher, the nasals more elevated, and the premaxillæ less bent downwards than in a typical skull of the Steppe variety.

In Clydesdales with a nearly straight profile—a type more common a generation ago than now—the face is wider and less bent, and the nasals are more prominent. In such cases, ancestors of the Forest type have prevailed.

It is rather remarkable that while in its skull a Shire horse usually very closely approaches the Steppe type, in its limbs and hoofs it as often presents the characters of

* In the skull of a Shire horse (Starlight) in the British Museum, the frontal index is 51·1, *i.e.* in its frontal index Starlight is almost identical with Prejvalsky's horse and with the 560 mm. Roman skull from Newstead.

the Forest type. This is doubtless largely the result of artificial selection, but the combination of pronounced Steppe and Forest characters in the same individual has been rendered possible because each variety tends to transmit almost unimpaired the points which have long counted most in the struggle for existence. In the case of the Steppe horse, long powerful jaws seem to be of the utmost importance; in the case of the Forest horse, broad hoofs (which imply thick fetlock joints and wide metacarpal bones) suitable for crossing swamps and marshes are absolutely necessary. Hence when the Steppe and Forest varieties are crossed, other things being equal, the half-breeds inherit a Prejvalsky-like head, but limbs and hoofs adapted for a forest life.

Some of the strains of the modern heavy horses are said to have originated from the crossing of English mares with stallions imported during the thirteenth century from

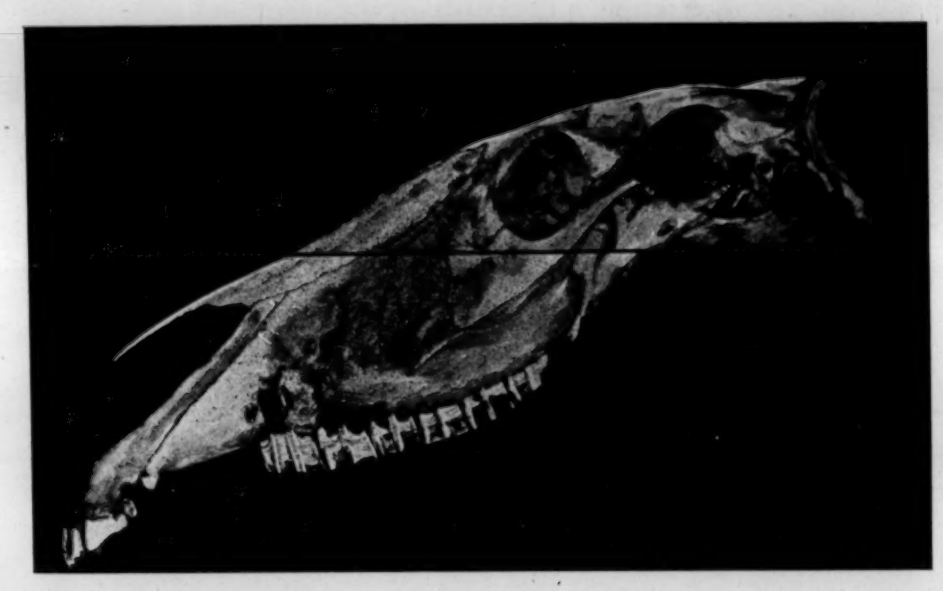


Fig. 2.—Lateral view of the skull of a cart-horse. In this skull the face is decidedly prominent below the level of the orbits, and strongly bent downwards on the cranium. In its measurements this skull agrees closely with the Roman skull figured (Pl. II. fig. 7), and with the skull of the four-year old Prejvalsky horse (fig. 1).

the Low Countries and the banks of the Elbe; but, as we have seen, horses practically identical, except in size, with the modern Shire breed were in the Newstead fort during the first and second centuries. In the skulls from Walthamstow there is evidence of a trace of Steppe blood. If these skulls belong to the Neolithic age, England had horses more or less allied to the modern Shire long before the Roman invasion.

Only the Steppe and Forest varieties seem to have taken part in the making of typical members of the Shire breed; but in Clydesdales there is evidence, now and again, of Celtic or Libyan blood.*

The Hackney breed, a recent blend of several varieties, includes animals of very different types; amongst others, a "Roman-nosed" type. Recently on examining the skull of a Hackney with a convex profile, I found that the face was as much bent on the

* Evidence of Celtic blood we have in the full eyes, small ears, and a more or less perfect tail-lock, and at rare intervals of the all but complete absence of hind chestnuts.

cranium as in the three-year-old Prejvalsky horse, which implies that "Roman-nosed" Hackneys have inherited some of their characters from the Steppe variety.

One of the best known Indian breeds of horses is the Kattiawar. This breed, according to Major-General TWEEDIE, is remarkable for its hardy constitution, power of endurance, and indomitable temper. RIDGEWAY says: "There can be no doubt that the Kattiawar horse is a cross between the dun-coloured horse of Upper Asia and the Arab, and, the better bred, the more of the latter blood there is in their veins." I recently received from Lord ARTHUR CECIL the skull of a Kattiawar mare imported from India some years ago. When alive, this mare looked as if saturated with Arab blood, but she had the indomitable temper characteristic of her race.

An examination of the skull (fig. 3) indicates that the Kattiawar breed has been mainly derived from the Steppe and Forest varieties—that the Forest horse has

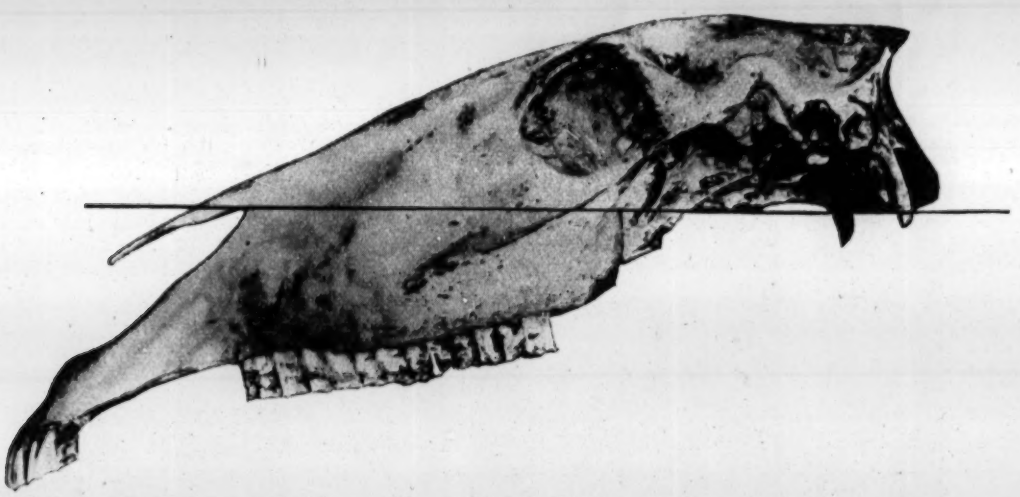


FIG. 3. Lateral view of the skull of a Kattiawar mare. In this skull the ace is not so bent on the cranium as in Prejvalsky's horse (fig. 1), but it is more arched between the highest point of the cranium and the distal parts of the nasal bones, and the face is relatively longer—nearly as long as in the bent Roman skull (Pl. II. fig. 7). This skull is especially interesting because in its measurements it closely approaches the skull of the English race-horse Orlando, ram-headed Barbs, and horses of Sanson's Dongola strain, and the numerous Arabs with a prominence extending some distance above and below the level of the orbits. The shortness of the post-orbital region, taken along with the great length and the curvature of the face, clearly indicates that at least some of the Kattiawar horses are intimately related to Prejvalsky's horse.

contributed in some cases to the making of this Indian breed is indicated by the length of the body. But the long neck and oblique shoulders usually met with in Kattiawar ponies clearly indicate that they include, amongst at least their more recent ancestors, horses of the Plateau type.

A very considerable number of Arabs resemble the Kattiawar mare in having a prominence between the eyes, while the Dongola variety described some years ago by SANSON, as well as many Barbs, might almost be described as ram-headed. It may be confidently predicted that in Arabs and Barbs, and other horses of the Oriental type with a convex profile, the skull will be found to be more or less bent on the cranium—a sure indication of descent from ancestors akin to Prejvalsky's horse.

In skulls of Irish hunters the profile is often convex and the face strongly bent on the cranium. This implies that Irish hunters are often saturated with Steppe blood,

probably originally introduced from Spain. If the temper of the Kattiawar horse merits the term indomitable, still more is this term applicable to the temper of the wild horse. Having decided to proceed in a given direction, Prejvalsky's horse is difficult to turn aside—for ordinary obstacles are either cleared or broken down.

A yearling stallion placed in a loose-box on arriving at Penycuik, some years ago, scrambled over a door considerably higher than himself; and a mare now in my possession sometimes walks deliberately up to a barbed-wire fence within an inch of her own height, and apparently without effort leaps over. The same mare also frequently enters a small stream and walks under a bridge to a patch of grass she has a liking for. Horses of the Forest type can hardly at first be persuaded to cross water—they have a strong inherited dislike of anything that may lead to their being bogged. If the Irish hunter, as his skull so clearly suggests, includes a Prejvalsky-like variety amongst his more dominant ancestors, we can understand his determination and staying power, and especially his facility in scrambling over walls, clearing fences, and usually without hesitation crossing streams and ditches.

I mentioned that Professor NOACK believed that he had conclusively proved Prejvalsky's horse to have an affinity to the pony. Judged by the form of the skulls it is evident that Prejvalsky's horse and the Celtic pony represent extreme types; but if by a pony is meant any horse under a certain size, then NOACK is quite right in his contention. Some time ago I received from Sulu—a small island not far from Borneo —a skull which, in its profile, and in the relation of the face to the cranium, the teeth, and the narrowness of the groove between the occipital condyles, is almost identical with the skull of a three years old Prejvalsky horse. As this skull belonged to an animal under 12 hands in height, it supports NOACK's view; but it at the same time shows how important it is, when speaking of ponies, to mention the race or variety to which they belong.

One of the questions asked by SALENSKY is—"Had Prejvalsky's horse in the past a wider geographical distribution than it has to-day?" In the *Reliquiæ Aquitanicæ* there is a reproduction of an engraving of a horse on a piece of horn found in the La Madelaine Cave. It is no exaggeration to say that this engraving (fig. 4) emphasises the chief points of Prejvalsky's horse better than any of the drawings or photographs of the specimens recently imported from Mongolia. The engraving (probably the work of a member of the Solutrian tribe of Palæoliths) brings out the heavy head, long face, and short back, but especially the peculiarities of the tail. It shows better than any recent drawings that the hair of the upper half of the dock is short, and sometimes bristles out at nearly right angles to the long hair growing from the rest of the dock. The writer of the description of this engraving in the *Reliquiæ Aquitanicæ*, says: "Why, however, the old artist roughened the hair near the root of the tail it is difficult to say." Now that we have had an opportunity of studying the tail of Prejvalsky's horse, we realise that the old artist roughened the hair near the root of the tail because nature

had left the tail of this particular animal in what seems to us an unfinished condition.

Further evidence of the existence of horses of the Steppe variety we have in osseous remains found in the Pleistocene deposits of the Rhine valley.

If the Steppe horse was in the south of Europe towards the end of the Palæolithic period, it doubtless about the same time reached in Asia as far south as the Himalayas.

If it is admitted that horses of the Steppe type ranged from the south of Europe to the Himalayas about the end of the Palæolithic period, there is no difficulty in accounting for the horses of Spain, South-Western Asia, and Northern India having to-day very marked affinities to the wild horse (*E. prejvalskii*) now limited in its range to the western portion of the Great Gobi Desert.

I have already stated that the Forest variety has played an important part in forming the Shire and Clydesdale horses. It may now be added that it has almost

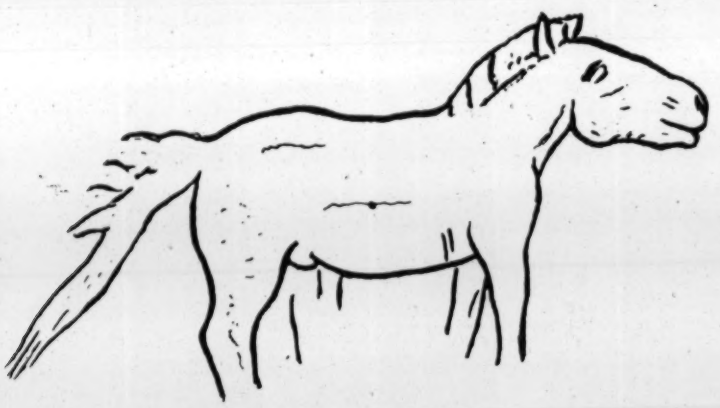


FIG. 4.—Outline of a horse carved on a piece of horn from the Madelaine Cave. This horse, in its head, and especially in its "roughened" tail, forcibly suggests the wild horse (*E. prejvalskii*) which still inhabits the Great Gobi Desert.

certainly taken part in forming all kinds of horses: (1) in which the back is long—includes six vertebræ in the lumbar region; (2) in which the hind-quarters are rounded and the tail set-on low; (3) in which the metacarpals are short and wide, and the fetlock joints thick, the pasterns short, and the hoofs broad; and (4) in which there is a short, broad, dished face, which, as in the elk, becomes prominent above the level of the nostrils (fig. 5).

Evidence of the Forest blood is especially common in the north-west of Europe, in, *e.g.*, the Gudbrandsdal and fjord horses of Norway,* in the stout, thick-set horses of the Highlands and Islands of Scotland (Pl. III. fig. 9), in the thick-set Shetland ponies, and in the small, long, and low horses of the Faroe Islands and Iceland. Further, the Forest type, in a nearly pure form, is also represented in Korea and other parts of Asia.

In Pleistocene times horses of the Forest type were common in the south of England. In the British Museum may be seen the upper portion of the skull of a Forest horse from Ilford, Essex, and a number of metacarpals from Kent and Essex

* MARSHALL, "The Horse in Norway," *Proc. Roy. Soc. Edin.*, vol. xxvi. pt. 1.

so broad and short that the length is only from 5·5 to 5·8 times the width of the middle portion of the shaft.

At the end of the Ice Age the Forest variety seems to have been common in the vicinity of the Rhone. The Stone Age deposits at Solutre contain the remains of numerous horses with the thick joints and broad hoofs, highly characteristic of the Forest type. There has not yet been discovered a representation of a Forest horse made during the Palæolithic age to equal the engraving of the Steppe horse found in the La Madelaine Cave, but one of the drawings (fig. 6) from the Combarelles Cave brings out all the more striking points of the Forest variety.

For some years ponies have attracted considerable attention, but the question what is a pony? has not yet been answered. On the assumption that "no breed of horses

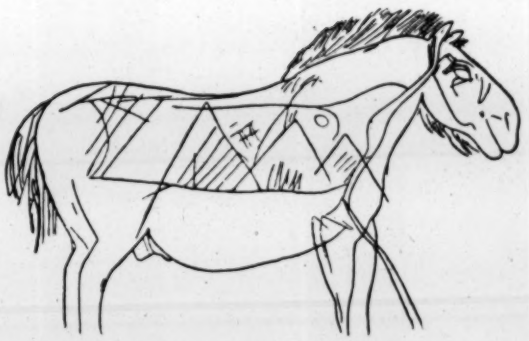


FIG. 6.—Drawing of a horse with an elk-like nose, short neck, stout body, rounded hind-quarters, and well-furnished tail. The original was probably a horse of the Forest type. Combarelles Cave. Palæolithic period.

FIG. 5.—Head of a horse of the Forest type with a short broad head, an elk-like nose, and a long upper lip.

possesses any distinctive characteristic which seems to distinguish it from other breeds," it has hitherto been the practice to speak of horses of all kinds which happened to be under a certain size as ponies. Sometimes horses under 13 hands (52 inches) are regarded as ponies, but at other times the limit is 12 hands (48 inches), or (*e.g.* in the case of Polo ponies) 14·2 hands (58 inches). One result of regarding all horses under, say, 13 hands as ponies is, that members of the Steppe and Forest varieties, though differing fundamentally from, are classed with, members of the Celtic variety. The practice of speaking of all kinds of horses under a given size as ponies is likely to continue, but in future, when it is desired to convey some idea of the kind of pony meant, writers will probably mention to which variety or race the pony in question is most intimately related. Breeders of ponies seem to be agreed that a typical pony should have a small, fine head, large full eyes, small ears, good shoulders, and clean limbs; and further, that ponies, in addition to being active, keen, and intelligent, are extremely pleasant to ride. The small horses which come nearest to this description

belong to the Celtic section of the Plateau variety. Hence small horses of the Celtic type, *i.e.* small flat-nosed horses with only two callosities, may be regarded as true ponies. Small members of the Steppe and Forest varieties are best spoken of as dwarf horses.

During the last ten years I have had under more or less constant observation ponies from the Faroe Islands and Iceland, from Shetland and the Hebrides, Connemara and Achill Island, Wales, Exmoor, and the New Forest, Norway and Russia, Mongolia and Java, and I have seen a great many ponies in the West Indies and Mexico. Of thirty ponies under 13 hands now in my possession, four have neither hind chestnuts nor ergots, in nine hind chestnuts are absent, in eight one hind chestnut or one or more of the ergots are wanting, four have the chief points of the Forest variety, one in its head and one in its tail closely resembles Prejvalsky's horse, and two have a remote resemblance to Prejvalsky's horse. Of those without one or more callosities, four have a well-marked tail-lock, and in eleven the tail-lock is fairly well developed.

Of a hundred Shetland ponies specially examined, eight, except in their colour, had the external points of the Celtic variety, twenty-five had most of the points of the Forest variety, in sixty-two the points of the Forest and Celtic varieties were unequally blended, two in the head, mane, and tail might have been Prejvalsky hybrids, while three had a remote resemblance to the Steppe variety.

In their affinities, Iceland ponies, apart from their colour, differ but little from Shetland ponies.

Of the other kinds of ponies mentioned, I can only speak with any certainty of those in Achill Island and Connemara in the west of Ireland, and of the ponies in the district of Oaxaca in the south of Mexico. In Achill Island in 1905 (notwithstanding recent infusions of alien blood) Celtic characters still prevailed, but in Connemara "Roman-nosed" ponies (*i.e.* ponies saturated with Steppe blood) and ponies of the Forest type were decidedly more common than ponies presenting Celtic characters.

When investigating the ponies of South Mexico, I was especially struck with the frequent absence of hind chestnuts, and that in some cases there was a vestige of the Celtic tail-lock. In Jamaica, as in Mexico, ponies without ergots or hind chestnuts were frequently met with.

As to what extent the small horses of Asia belong to the Celtic variety, I am unable to offer an opinion. The skull from Sulu indicates that some of the horses of south-eastern Asia are allied to the Steppe variety, but, on the other hand, the Java ponies in my possession, like many Arabs, want the ergots, and have skulls of the Celtic type. As far as I can learn, the Celtic variety is not represented in north-eastern Asia; nevertheless I have a photograph of a Japanese cavalry officer mounted on a pony without hind chestnuts. The general conclusion arrived at by studying small horses is that the majority consist of a blend of the Plateau and Forest varieties—the finer the head and the fewer the callosities, the larger, as a rule, the proportion of Plateau blood; the broader the face, the longer the body, the rounder the quarters, and the broader the fetlock, joints, and hoofs, the larger the proportion of Forest blood.

One of the small skulls from Newstead differs more decidedly from skulls of the Forest and Steppe varieties than any skulls of modern Celtic ponies I have hitherto had the opportunity of examining. From this it may perhaps be inferred that at the beginning of the Christian era typical Celtic ponies were more common than is the case now.

Horses of the so-called Oriental type.—I have had occasion again and again to refer to Professor RIDGEWAY'S work on the *Origin and Influence of the Thoroughbred Horse.* The object of this book is to prove (mainly by the use of the deductive method) (1) that in the remote past there was evolved in North Africa a fleet, docile bay horse, characterised by a fine head, narrow hoofs, and the absence of the hind chestnuts, by a star on the forehead and white points, by a high set-on tail and a tendency to stripes—a horse having a general resemblance to the best Arabian and Barbary horses of to-day; and (2) that by the blending of this North African (Libyan) variety with the dun and white horses of Europe and Asia in varying degrees, all the improved breeds in the world were produced.

It will be remembered that the excavators found at Newstead a number of long, narrow skulls, which were probably connected with the presence of Gaulish auxiliaries from between the Alps and the Rhone. These skulls, except in size, were found to be almost identical with the small Newstead skulls of the Celtic type, and they very closely agree with the skulls of certain modern high-caste Arabs. From this it may be inferred that the Celtic pony, the Arab-like (Libyan) horses of the second century, and modern Arabs of the highest type, have all sprung from the same stock.

I have given reasons for the view that in prehistoric times the Celtic variety was widely distributed in Europe; in all probability it occurred in various parts of Asia, and, it may be added, it had ample opportunities during the Ice Age of reaching North Africa. In an attempt to answer the question, Where was the original home of the variety to which the Arab-like Newstead skulls belonged? one has to consider where in bygone days the conditions lent themselves to the evolution of horses of the Plateau or riding type. That Arabia was not the birthplace of the fine-headed, slender-limbed fleet steeds which reached the south of Europe in considerable numbers before the Christian era, will be admitted if, as seems highly probable, the Arabians at the beginning of the Christian era had not yet acquired horses.

In Homeric times there were dun-coloured horses in Greece. Achilles had two long-maned swift horses, a dun and a dapple-dun, that flew as swift as the winds. In Thrace there were white horses whiter than snow and "for speed like the winds." The Sigynnæ, some centuries later, had small flat-nosed horses, which when yoked under a chariot were very swift.

The flat-nosed and long-maned horses could not belong to the long-headed "Roman-nosed" Steppe variety, and the swift horses could hardly belong to the slow-moving Forest type, which implies that, like the small swift horses of the ancient Britons, they belonged to the Celtic variety, or were at least saturated with Celtic

blood. But while the Celtic race may have led to considerable improvement in the horses of south-eastern Europe, there is no evidence that in any part of Europe it gave rise to a long-limbed, long-necked race built on the lines of modern Barbs. Whether in south-western Asia, by blending the Celtic with the Steppe or the Forest variety, fleet long-limbed breeds were formed some centuries before the Christian era, it is impossible to say. In the meantime, following RIDGEWAY, we must turn to North Africa as the most likely home of the Arab-like horses made use of for improving the native breeds of north-west Europe from the second century B.C. onwards.

In support of the view that in prehistoric times there existed in Europe a variety of a yellow dun-colour with a small head, a heavy mane, and a tail-lock with twenty-three dorso-lumbar vertebræ, but with neither hind chestnuts nor ergots, one has only to mention that ponies having these characteristics are still in existence. But it is apparently not possible to produce from North Africa horses having the characters RIDGEWAY ascribes to his Libyan horse.

SANSON, some years ago, described a North African variety (the *E. c. africanus*), which agrees with the Celtic variety in having no hind chestnuts, and in having only twenty-three dorso-lumbar vertebræ; but unfortunately this, the Dongola variety, has a ram-like head, which implies that it is saturated with Steppe blood.

Perhaps one may gain some idea of what happened in North Africa in prehistoric times from what has happened in Mexico during the last five hundred years.

From the landing of Cortes in 1519 till the conquest was completed in 1521, over a hundred horses of various types and colours were introduced.* After 1521, as adventurers poured in, the number of horses was rapidly increased, and ere long large herds were formed in various parts of the great Mexican plateau.

Since its conquest, until a few years ago, Mexico has been, as a rule, so unsettled that in at least the case of horses natural selection has had a free hand. The result of the environmental selection on the Mexican plateau has been in some districts the elimination of horses of a decided Steppe and Forest type, and the preservation of horses which more or less accurately conformed to the Plateau type. The conditions, as far as horses are concerned, on the Libyan plateau in prehistoric times perhaps did not differ materially from those during recent times in certain parts of the Mexican plateau.

The somewhat modified members of the Celtic variety which during or immediately after the Ice Age reached North Africa from Southern Europe may have found little difficulty in adapting themselves to a plateau life, while the Steppe and Forest varieties, finding their surroundings uncongenial, may have barely succeeded in maintaining themselves outside certain limited areas.

As already mentioned, RIDGEWAY thinks the Libyan plateau in course of time produced a small, fleet, docile bay horse, with white 'stockings,' a star on the forehead, a high set-on tail, long narrow hoofs, and a tendency to stripes, but without ergots and

* Cortes, *e.g.*, took with him nine chestnuts and three grey horses, one sorrel, one light-dun, one yellow-dun, and one dark-coloured horse. RIDGEWAY, *Origin and Influence of the Thoroughbred Horse*, p. 268.

hind chestnuts. The horses in South Mexico of the riding type are, as a rule, bays with dark points, without either a dorsal band or bars on the legs, with the tail in a line with the backbone, but not set-on high, as in many Arabs, and the hind chestnuts and ergots frequently absent. I have never seen an Arab or a Barb without hind chestnuts, and I have only heard of one English thoroughbred without hind chestnuts.

An Iceland, a Shetland, or a Highland pony may in make very closely agree with a Forest horse, and yet be without hind chestnuts or ergots, or both. A horse without hind chestnuts or ergots is hence not necessarily a member of the Plateau variety; but when, in any given district or breed, these callosities are frequently absent, it may be assumed there is a decided substratum of Plateau blood.

It is rather remarkable that the chestnuts are frequently absent in Mexican ponies, and rarely absent in Arabs, Barbs, and thoroughbreds. Is the explanation, that the Celtic variety was at one time common in Spain, from whence come the progenitors of the horses of Mexico; or is it that, as the Dongola variety of SANSON is a blend of the Plateau and Steppe varieties, RIDGEWAY'S Libyan variety is now almost invariably more or less saturated with Forest blood?

I have come across few horses from North Africa without a trace of Steppe blood. One such horse may be said to prove his Steppe origin by his foals invariably having a very long face. When, however, horses having the points of SANSON'S Dongola race are crossed with mares of the Celtic type, they often have offspring which in make very closely approach RIDGEWAY'S ideal Libyan. Crosses of this kind met with in North Mexico were frequently without ergots, and in some cases the hind chestnuts were either very small or absent. A great many Arabs, especially white Arabs, with a short back, a high set-on tail, and narrow hoofs, have a distinct affinity to the Steppe variety, while others have the long back and the short broad face of the Forest variety. A chestnut stallion built on the Forest type, for some time in my possession, was the fastest and best-tempered Arab I have ever come across, while a bay stallion, nearly as fast as the chestnut, imported by Lord ARTHUR CECIL, had also Forest affinities—the dorsal band was distinct, and there were clear-cut bars in the vicinity of the knees and hocks. In both these stallions the hind chestnuts were large, and all the four ergots were present. The short-backed Arabs, often longer in the limbs and in the neck than Arabs of the Forest type, are frequently without ergots, and the hind chestnuts are often small. Those short-backed Arabs have not, as far as I have seen, a tendency to stripes, neither have they the tail, as a rule, set-on specially high; and though gifted with wonderful staying power, they are not, as far as my experience goes, as fleet as Arabs with an affinity to the Forest variety.

For want of material it has not been possible to make much progress with a study of the English thoroughbred. But from an examination of the skeletons of Stockwell (British Museum), and Orlando (College of Surgeons Museum, Lincoln's Inn Fields), and of a number of skulls, it is evident that though the Plateau variety forms the foundation of the English race-horse, it is frequently saturated with Steppe blood, *i.e.*

has in part sprung from the same coarse-headed variety which played a chief part in the making of the great English Shire horse.

I have much pleasure in expressing my indebtedness to the Scottish Society of Antiquaries for allowing me the opportunity of studying the skulls and other bones of horses found during the exploration of the Newstead fort; and in tendering my grateful thanks for valuable help to Mr James Curle of Priorwood, Melrose, to Mr George Macdonald, LL.D., of the Scottish Education Department, to Professor D. J. Cunningham, F.R.S., of the University of Edinburgh, and to Professor O. Charnock Bradley, D.Sc., of the Royal Veterinary College, Edinburgh. I may add that but for the information gained from experiments, towards the cost of which contributions were received from the Earl of Moray Research Fund of the University of Edinburgh and from the Carnegie Trustees, it would not have been possible to arrive at the general conclusions set forth in this paper.

Table I.

Skull.	Forest Variety, Roman.	Forest Variety, Iceland.*	Steppe Variety, Roman.	Steppe Variety, Prejvalsky's Horse.*	Plateau Variety, Roman ? British.	Plateau Variety, Roman ? N. Africa.	Plateau Variety, Celtic Type.*	Arab "Jerboa," Brit. Mus.	Thoroughbred "Orlando," C. S. Mus.	Thoroughbred "Stockwell," Brit Mus.	Thoroughbred "Bend Or," Brit. Mus.	Shire "Starlight," Brit. Mus.
Total length, . . .	547·0	506·0	560·0	518·0	494·0	534·0	485·0	530·0	562·0	583·0	562·0	678·0
Facial length, . . .	373·0	336·0	399·0	371·0	338·0	372·0	333·0	368·0	389·0	412·0	385·0	463·0
Frontal width, . . .	228·0	206·0	223·0	187·0	185·0	203·0	192·0	205·0	218·0	212·0	221·0	237·0
Frontal index, . . .	61·2	61·3	50·3	50·9	54·1	54·0	57·6	55·7	56·0	51·4	57·4	51·1
Cranium: length, . .	194·0	165·0	165·0	167·0	156·0	182·0	170·0	...	...	...	...	...
„ width, . .	106·0	105·0	96·0	99·0	108·0	102·0	100·0	...	...	...	...	...
Cephalic index, . . .	67·2	63·6	58·1	60·0	69·2	66·0	58·8	...	...	...	...	...
Orbital index, . . .	93·0	96·8	90·0	80·8	82·0	80·8	94·9	86·5	...	72·3	80·8	79·0

* The frontal and orbital measurements and indices of these three skulls are taken from a paper communicated to the Royal Society, November 1906, by Prof. O. Charnock Bradley, D.Sc., *Proc. Roy. Soc. Edin.*, vol. xxvii. pp. 46–50.

DESCRIPTION OF FIGURES.

Plate I.

Fig. 1. View from above of a skull of the Forest type. From a skull of the Steppe type this skull differs in having a short, broad face. Newstead fort.

Fig. 2. Lateral view of a skull of the Forest type in which the face is nearly in a line with the cranium. The outline of the face is distinctly concave. Iceland pony.

Fig. 3. View from below of a skull of the Forest type. The space between the occipital condyles measures 7 mm.,—in a skull of the Steppe type the condyles may only be separated by a space of 2 mm. Newstead fort.

Fig. 4. View from above of the skull represented in fig. 7. Note the great length of the face, long nasals, and narrow premaxillary region.

Fig. 5. Skull of a young Prejvalsky horse (age about 15 months). At this age the face is nearly in a line with the cranium, as in adult members of the Forest variety.

Plate II.

Fig. 6. Skull of the Forest type, with the face nearly in a line with the cranium, as in the elk (*Alces*). A line carried through the basi-cranial axis emerges well below the tips of the nasals. Newstead fort.

Fig. 7. Lateral view of a skull of the Steppe type, in which the face is bent downwards on the cranium as in sheep. A line carried through the basi-cranial axis emerges between the anterior margin of the orbit and the tip of the nasals. Owing to the great length of the face and to the backward position of the orbit, the post-orbital portion of the skull is relatively shorter than in the Forest skull represented in fig. 6. Note the difference in the shape of the orbit in figs. 6 and 7. Newstead fort.

Plate III.

Fig. 8. A typical yellow dun 12-hands Celtic pony mare, a member of the northern section of the Plateau variety. In summer coat, with the mane removed and most of the tail-lock shed. Two of the ponies in the Newstead fort probably belonged to this small, slender-limbed, active, intelligent race.

Fig. 9. A Highland deerstalker's pony of the Forest type. Note short neck, round quarter and low set-on tail.

Fig. 10. On the right is the head of a Mexican horse of the Plateau type. Note that the head is small, the eye large and full, while the muzzle is fine. On the left is the head of a horse with a very long face and long ears as in *E. prejvalskii*.

Fig. 11. A Prejvalsky horse (about 2½ years old), to illustrate the external characteristics of a member of the Steppe variety. To a horse of this type English Shire horses, "Roman-nosed" Clydesdales and Hackneys, and ram-headed Barbs and English thoroughbreds, owe some of their most striking characteristics.

Fig. 12. Head of the Prejvalsky horse in fig. 11, to show that the eyes are near the long ears but far from the nostrils, as in the majority of cart horses, and as in the long-faced Mexican horse in fig. 10.

Figs. 1 to 7, 9 and 12, and text-figures 1 to 3 and 5 from photographs by G. A. Ewart, figs. 8 and 11 from photographs by Captain Hayes, and fig. 10 from a photograph by E. F. Ewart.

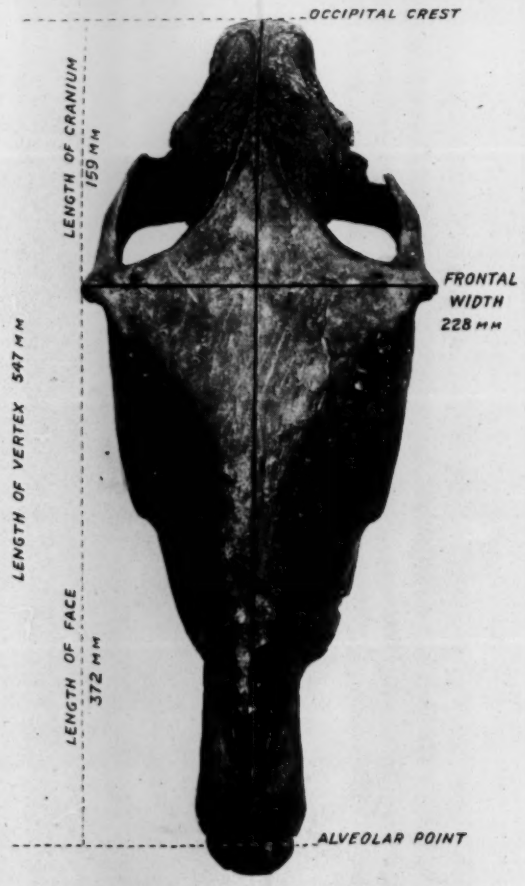


Fig 1.

Fig. 3.

Fig. 4.

Fig. 2.—Forest Variety, adult.

Fig. 5.—Steppe Variety, *circa* 15 months.

PLATE II.

FIG. 6.—Forest Variety, Newstead Fort.

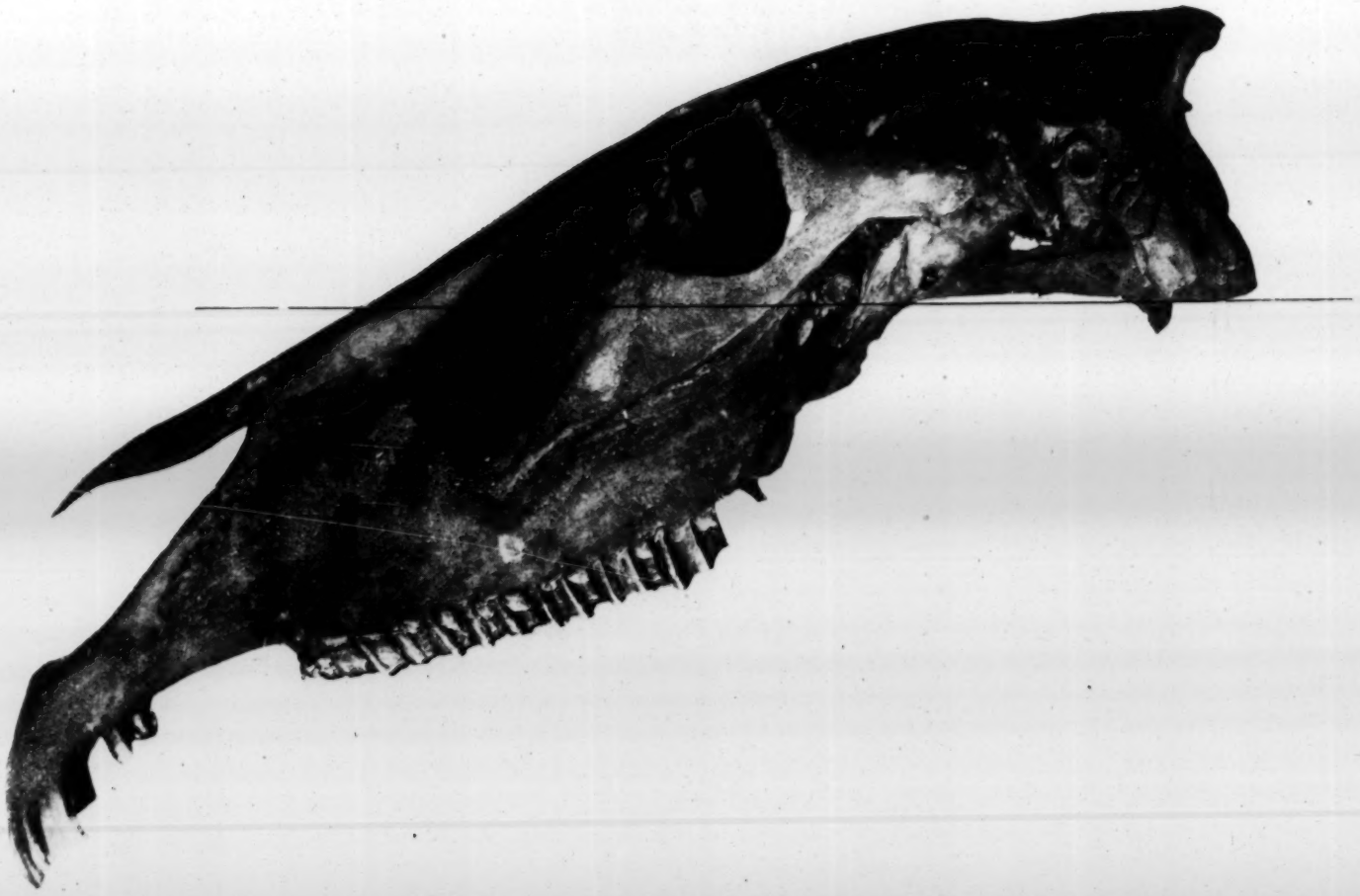


FIG. 7.—Steppe Variety, Newstead Fort.

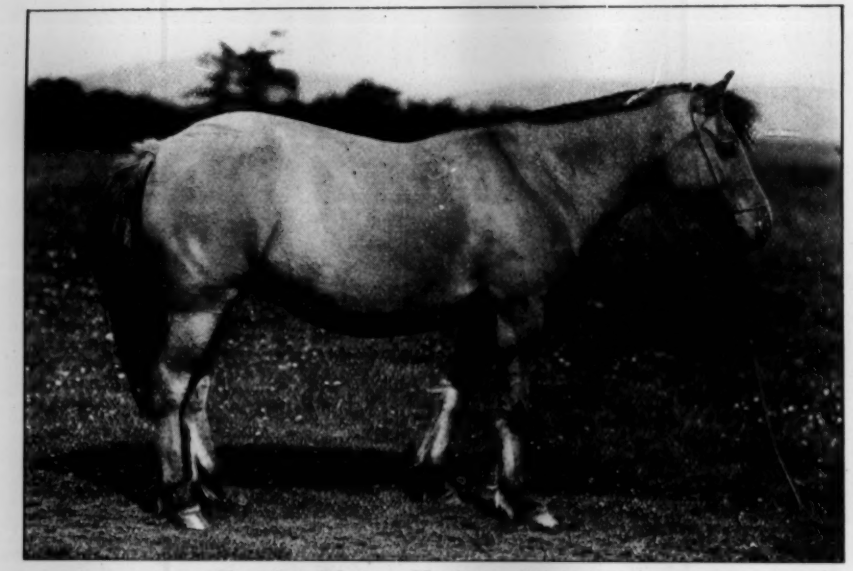


Fig. 8.—Plateau Variety, Celtic Race.

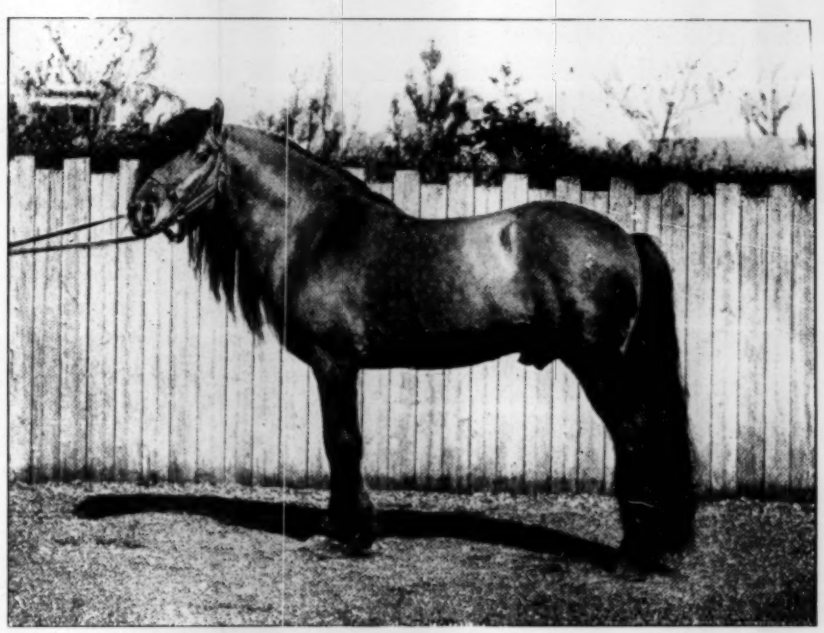


Fig. 9.—Forest Variety.

Fig. 10.—Mexican Horses.

Fig. 12.—Steppe Variety.

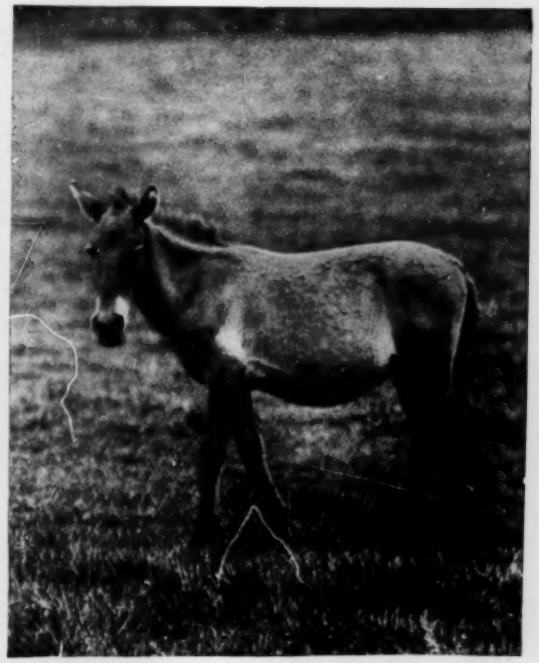


Fig. 11.—Steppe Variety.

XXI.—Results of Removal and Transplantation of Ovaries.

By F. H. A. Marshall, D.Sc., Carnegie Fellow and Lecturer on the Physiology of Reproduction, and W. A. Jolly, M.B., Assistant to the Professor of Physiology, University of Edinburgh. (From the Physiological Laboratory, University of Edinburgh.) (With Two Plates.)

(Read December 3, 1906. MS. received December 6, 1906. Issued separately May 8, 1907.)

It is well known that double ovariotomy, when performed prior to puberty, exercises a prejudicial effect not only upon the generative organs but also upon the whole organism. There is, however, some disagreement as to the results of this operation when performed after puberty, and particularly in regard to the occurrence of heat or menstruation.

It is the purpose of this paper to adduce further evidence upon this question, as well as to describe experiments the result of which indicates that the nature of the ovarian influence is chemical rather than nervous.

Numerous instances have been cited of the occurrence of menstruation after double ovariotomy. Thus three cases have been recently described by Doran (1905) in each of which the ovaries were believed to have been removed, and the greater part of the uterus was also removed, but where menstruation occurred at irregular intervals after the operation.* Doran, however, records a large series of other cases in which menstruation ceased after ovariotomy. In a further case described by Pozzi, the recurrence of the catamenia after removal of the ovary is thought to have been due to the presence of a uterine fibroma; but Pozzi makes no suggestion as to why such a fibroma should have the effect supposed. A case of greater interest has lately been recorded by Pinard, in which ovariotomy was performed for *mollities* during pregnancy. After delivery the catamenia returned, and also the bad symptoms. Hysterectomy was then performed, and on inspection ovarian tissue was detected in the position from which the ovaries had been removed. It would seem probable that the other cases of menstruation taking place after double ovariotomy are to be similarly explained, on the assumption that the removal was not quite complete and that the ovarian tissue which remained underwent hypertrophy. That this interpretation is correct is rendered the more probable in view of the cases referred to by Doran (1902), in which pregnancy occurred after the supposed removal of both ovaries. Since the publication of Doran's paper in which the literature is given, a further case of pregnancy after double ovariotomy has been put on record by Meredith (1904).

It is a not uncommon practice among veterinarians to remove the ovaries of dogs

* Bell (1906), referring to such cases in a recent paper, is disposed to ascribe the continuance of menstruation to the presence of the uterus, which he regards as sufficient for the purpose even in the complete absence of the ovary.

in order to prevent them from breeding. We understand from Principal M'CALL, of Glasgow, that normal heat does not occur in dogs on whom this operation has been performed.

Ovariotomy is also sometimes performed on mares, and usually with the object of repressing those vicious symptoms which so often occur during the œstrous periods and render the animals at such times almost or quite unworkable. Details of fifty consecutive cases of ovariotomy in troublesome mares are given in two papers by HOBDAY (1902, 1906), who shows that the operation is frequently followed by perfectly successful results. From these papers it does not appear certain that œstrus is completely prevented after the removal of the ovaries, but the violent symptoms which rendered the mares useless for work were in nearly every instance suppressed. In one case ovariotomy was undertaken to prevent œstrus, and the result was regarded as having been "satisfactory." Other mares are described as having been operated on because they were "always in œstrum," and so, presumably, unworkable, and in these cases also the result of the ovariotomy is said to have been satisfactory.

The statements of certain writers regarding the condition of the uterus subsequent to double ovariotomy are in opposition to the views of those who hold that heat and menstruation may occur after the performance of that operation. Thus KNAUER (1900) says that removal of the ovaries in rabbits brings about a premature menopause, the uterus undergoing atrophy. Similar statements have been made by SOKOLOFF (1896), HOFMEIER, BENKISER (1891), and BUYS and VANDERVELTE (1894). HOFMEIER and BENKISER, however, ascribe the degenerative changes in the generative organs after ovariotomy to an insufficiency in the blood supply consequent upon the operation of removal, while BUYS and VANDERVELTE are disposed to regard these changes as being the indirect result of an assumed severance of nerves passing to the uterus and vagina. LIMON (1904), on the other hand, states that he found no sign of atrophy in the generative organs after the transplantation of the ovaries to an abnormal position, and, therefore, that the respective explanations offered by HOFMEIER and BENKISER and by BUYS and VANDERVELTE are inadequate. But LIMON does not appear to have made more than a superficial examination of the organs to which he refers; he mentions also that the experiments of KNAUER, RIBBERT, and RUBINSTEIN point to the same conclusion as his own, and support the view that the proper nutrition of the uterus is dependent upon the existence of an internal ovarian secretion.

Our own observations on this matter are such as seem to us definitely to exclude the possibility of the recurrence of normal heat after the ovaries have been removed for a period longer than a few months.

The blood supply of the uterus is derived largely from the uterine artery which is given off in the pelvis, and is in no way interfered with by the operation of ovariotomy. The ovarian artery in the experiments described below was necessarily severed at a point a little short of its entrance to the ovaries, and in all our experiments the blood supply of the uterus may be said to have been unimpaired.

Effects of Castration.

With the object of observing what changes, if any, are brought about in the uterus by the removal of the ovaries, we have performed ovariotomy in thirty-three rats. Both ovaries were removed by an anterior median incision. The rats were killed at periods varying from two and a half to eight months after operation, and the uterus examined histologically. In the great majority of cases the uterus has been found to exhibit divergence from the normal in a greater or less degree. It is small and atrophied. The mucosa is thin and poor in cells, the mucosal glands are small, while the connective tissue is increased in amount. In some cases, as in fig. 6, which represents a uterus examined six months after castration, the histological changes are very marked: the muscular wall is thinned and its connective tissue increased; the mucous membrane is in a condition of great fibrous overgrowth, and the glands are hardly recognisable.

All stages of degeneration can be seen from the condition found about two months after operation, where the uterus is small and shows commencing atrophy, to the extreme degree described above.

In several cases the uterus was found to have become distended with clear fluid, and on microscopical examination the uterine wall was seen to be thinned, the mucosa being represented only by a few cells and some fibrous tissue, and the lining epithelium converted into a stratified squamous epithelium.

In more than one instance an appearance resembling endometritis was observed after castration, the mucosa being swollen and the epithelium desquamated. There was in these cases no inflammation at the site of operation nor obvious source of septic infection, and the condition may probably be interpreted as a degenerative one.

In one case, where no atrophic appearances were presented by the uterus, a small portion of one ovary, in which at least two corpora lutea had become developed, was found, on post-mortem examination, to have been left behind at the operation.

The effect produced upon the uterus by removing the ovaries, and transplanting them to abnormal positions, will be discussed after we have described our experiments on ovarian transplantation.

Ovarian Transplantation.

The grafting of various organs of the body (such as the thyroid, suprarenal, kidney, etc.) in abnormal positions in the same individual, or in normal or abnormal positions in other individuals, has been attempted by numerous investigators with a varying amount of success. As a general rule, heteroplastic transplantation (*i.e.* from one individual to another) has been found far more difficult to carry out than homoplastic transplantation (*i.e.* in the same individual); while the latter, in the case of many organs, has not so far been successfully accomplished.

Transplantation of the testis has been attempted by Ribbert (1898), but without success, the grafted organ undergoing a rapid degeneration. Shattock and Seligmann

(1904), however, state that in attempting to remove the testes of fowls the organs in some cases broke up, minute fragments being left behind, and, becoming attached to the adjacent viscera or abdominal wall, continued to produce spermatozoa and act as functional glands. In these cases it would appear that transplantation was unintentionally affected.

Ovarian transplantation has been practised or attempted by various gynæcologists, surgeons and others. The grafts in some instances are described as having been successful; but histological descriptions of the transplanted ovaries are often omitted, and these when they are given are very rarely illustrated by figures. The only attempt, so far as we are aware, adequately to illustrate microscopic sections of transplanted ovaries, appears to be that of LIMON (1904), whose experiments in grafting do not seem to have been so successful as our own.

The cases described by MORRIS (1896), DUDLEY (1897), and GLASS (1899), in which ovaries were grafted into women whose own ovaries had been previously removed, have been mentioned in our previous paper (1905). It should be noted, however, that no record has been made (at least, so far as we are aware) of the further history of these cases since they were first published, and, although they have been described as successful, in the absence of post-mortem examination there is no direct evidence that this was the case.

The case recently described by MORRIS (1906) in which a woman with a grafted ovary (her own ovaries having been extirpated) is said to have become pregnant and given birth to a child about four years after the operation, is still more problematical. A possible explanation of this case is that a portion of one of the woman's own ovaries had been accidentally left behind at the time of the operation of removal and had subsequently undergone hypertrophy and given rise to the ovum, which afterwards became fertilised, just as in the cases described by DORAN referred to above. If this be the true explanation, there is no need to assume that the transplanted ovary had become functional. MORRIS states that the woman did not menstruate until four months after the transplantation had been effected, and then menstruated at irregular periods. There is no post-mortem evidence that in any of these cases the graft had been successfully attached.

CRAMER, of Bonn (1906), has recently recorded a case in which the ovary of a woman suffering from osteomalacia was removed and transplanted into a second woman whose genital organs were much atrophied. The operations were performed simultaneously. As a result of the transplantation the genital organs of the woman in whom the ovary was grafted are said to have become normal, menstruation started once more, and the breasts secreted colostrum. The author regards this case as affording further evidence that transplanted ovaries can maintain their functions.

The earliest attempts to transplant ovaries in animals seem to have been those of ROMANES, who refers to them in *Darwin and After Darwin*, vol. ii. (1895). These experiments were unsuccessful.

KNAUER (1896) removed an ovary from a rabbit and transplanted it upon the uterine horn of the same side in the same individual. After several months he killed the rabbit, when he found the grafted ovary, which contained Graafian follicles, some degenerate but some apparently healthy.

GRIGORIEFF (1897) performed a series of experiments in which he transplanted ovaries of adult rabbits to the broad ligament or the peritoneum of the vesico-uterine pouch. Subsequently he found that the grafts had become successfully attached and contained follicles in a state of complete preservation. In four cases pregnancy is stated to have occurred, the ova being supposed to have been derived from the grafted ovaries.

GRIGORIEFF also mentions two cases in which ovaries were transplanted from one individual to another (heteroplastic grafting). Both of these are said to have been successful, but no description is given of the transplanted ovaries.

ARENDT (1898), who attempted to transplant the ovaries of eleven rabbits to the broad ligament, was unsuccessful in all cases. This author criticises the results obtained by KNAUER and GRIGORIEFF, and concludes that in the cases of pregnancy described by the latter the ova were produced in fragments of untransplanted ovarian tissue which had been left in the normal position. ARENDT expresses doubts as to the possibility of successfully transplanting ovaries.

RIBBERT (1898), working on the guinea-pig, obtained results in homoplastic transplantation which, in a general way, are confirmatory of those of KNAUER and GRIGORIEFF. During the first month after transplantation the peripheral part of the grafted ovaries remained unaltered but the central part became transformed into connective tissue. At later periods, however, the central portion of the ovaries was again found to contain follicles. RIBBERT attributes this fact to the conditions of better nutrition which the ovaries had probably attained after a month of transplantation.

RUBINSTEIN (1898) was also successful in transplanting rabbits' ovaries to abnormal positions in the same individuals.

KNAUER, in a later paper (1899), has described certain further experiments in transplanting ovaries. These were to a great extent successful. KNAUER, however, states that a portion of the grafted ovary invariably died, but the remaining part in a large percentage of cases contained healthy follicles. Thirteen further cases are mentioned in which an attempt was made to transplant ovaries from one individual into another (heteroplastic transplantation), but each of these is reported as having been unsuccessful.

M'CONE (1899), in a preliminary report, briefly describes two cases of heteroplastic grafting. In one of these the ovaries of a rabbit were implanted in another rabbit (previously castrated), and the latter is stated to have subsequently given birth to five young. In a second experiment the ovaries of a bitch are described as having been successfully grafted upon a rabbit. Other experiments are mentioned in which homoplastic transplantation (*i.e.* transplantation in the same individual) of rabbits'

ovaries is said to have been effected. The accounts are very meagre, and do not appear to have been followed by a full report; this is the more to be regretted since other experiments of a similar nature are mentioned as having been in progress. In the absence of a full report stating the results of the entire series of experiments and entering into histological detail, we hesitate to express ourselves regarding the value of M'Cone's work.

Herlitzka (1900) has described forty experiments in which he tried to graft the ovaries of guinea-pigs upon the bodies of other individuals, some female and some male. The experiments were unsuccessful in all cases except one, the ovaries undergoing a process of degeneration with greater or less rapidity. The single exception was the case of an ovary which, after transplantation for forty-two days, was found to contain follicles with an apparently normal ovum. The ovary contained other follicles which were degenerate. In this experiment the ovary had been transplanted to the body of a female. Herlitzka describes those cases in which the ovaries are transplanted to new positions in the same individuals as homoplastic transplantations, while the cases in which they are implanted on other individuals he denotes as heteroplastic transplantations. We have adopted this terminology in the present paper.

Schultz (1900) has given an account of five experiments in which the ovaries of guinea-pigs were grafted upon the bodies of males. All the five experiments are said to have been successful. Schultz's results have been criticised somewhat severely in a further paper by Herlitzka (1900), who complains of insufficiency of detail in the descriptions of the experiments.

Foà (1900) has described a series of experiments in which the ovaries of newly born or very young rabbits were grafted in the normal position in older rabbits of various ages whose own ovaries had been removed. Some of the grafts are said to have taken successfully and even to have undergone growth after transplantation. In five other experiments the young ovaries were grafted without first removing the ovaries of the animals upon which the grafts were made, and of these three are said to have "yielded a positive result"; but no description of the grafts is given. In other cases in which embryo ovaries were grafted in old rabbits which had reached the menopause, the grafts degenerated very rapidly and were absorbed without leaving any trace.

Amico-Roxas (1901) has briefly described heteroplastic and homoplastic transplantation of sheep's ovaries, but without giving any account of the histological structure of the transplanted ovaries.

Morris (1903), whose cases of ovarian transplantation in the human female have already been referred to, has also mentioned that he carried out some experiments on heteroplastic transplantation in rabbits. He states that the grafted ovaries continued to furnish ova and to elaborate an internal secretion for some months, but that they then underwent degeneration. He does not, however, give any account of his experiments, and omits to state the evidence upon which he bases his conclusions that the transplanted ovaries continued to provide an internal secretion.

Limon (1904) performed four homoplastic transplantations of rabbits' ovaries, which were grafted on the peritoneum or between the muscles of the abdominal wall. The follicles all showed a tendency to degenerate; but the interstitial cells, on the other hand, after a short period of starvation subsequently recuperated, and acquired a condition of perfect vitality. There is, however, no mention of the Graafian follicles having done likewise, or of corpora lutea having been formed. Figures are given illustrating the recuperation of the interstitial tissue.

Basso (1905) has performed homoplastic grafts, and also heteroplastic, in rabbits and guinea-pigs. The ovaries were usually grafted on to the mesometrium. Some success was attained, especially in the homoplastic implantations. No figures, however, are given. In the heteroplastic implantations the stroma is described as having become necrotic Ovaries were also transplanted to males, and, since these were not less successful, the author concludes that presence of the testis did not exert any special inhibitory influence.

Bond (1906), in a recent paper on "Some Points on Uterine and Ovarian Physiology and Pathology in Rabbits," has referred to a few experiments in which he transplanted ovaries to abnormal positions in the same individuals (homoplastic grafts). Only one experiment appears to have been at all successful. In this case "a somewhat modified and degenerate corpus luteum of pregnancy" was found, after the ovary had been grafted for about a month, in a pregnant animal whose other ovary had been allowed to remain *in situ*.

Our transplantation experiments have been performed on rats.

I. Homoplastic Implantation.

The ovaries of twenty rats were excised and transplanted to another situation within the peritoneal cavity, being attached by means of a catgut stitch to the parietal peritoneum. Of these cases, the following eight may be described as entirely successful:—

1. The grafted ovaries (fig. 1) were allowed to remain for two and a quarter months. When examined, they were found to contain follicles and ova. The follicular epithelium was normal, and groups of interstitial cells were visible in the stroma. The germinal epithelium had disappeared from the outside of the ovary. Several large cysts, lined with squamous epithelium, were also present. The ovaries were examined in the month of January, *i.e.* before the breeding season of the rat.

2. The graft was here left for two months, and the rat was killed in the beginning of the breeding season. The graft contains follicles, and a large number of corpora lutea of apparently different ages.

3. This graft (fig. 2) was left for two months, and showed, on microscopic examination, follicles, ova, and corpora lutea. The rat was killed during the breeding season.

4. The graft was left for two and a half months, and exhibited follicles, corpora lutea, and a cyst. Killed during breeding season.

5. Graft left for three months. Normal corpora lutea and cysts were found present. Killed during breeding season.

6. Graft left for eight months. A few corpora lutea and follicles were present, with relatively large amount of stroma. This rat was killed in October, *i.e.* during the non-breeding season.

7. Graft left for five months. The ovarian stroma was unaltered. Some luteal tissue, follicles, and cysts were also present.

8. Graft left for six months. Shows follicles and corpora lutea.

In seven other cases of homoplastic implantation partial success was obtained. The tissue is recognisably ovarian, but has become considerably altered.

Five experiments must be described as unsuccessful, the grafted tissue either being entirely absorbed or replaced by connective tissue. Cysts were found present in each of these cases.

II. Heteroplastic Implantation.

Six operations were performed in which ovaries were removed from one rat and implanted on the peritoneum of another.

Two cases were attended with success.

1. The ovaries were removed from a rat and transplanted to the peritoneum of another whose own ovaries had previously been removed. The graft (fig. 3) was left for three and a quarter months, when the animal was killed. Examined microscopically, the graft showed ovarian stroma and corpora lutea. The two rats were possibly of the same litter, but this was not certainly known.

2. The ovaries were removed from a rat and transplanted to the peritoneum of another whose own ovaries were not removed. The two rats were of the same litter. The graft (fig. 4) was left for one and a half months; it contained follicles and ova. The stroma had become degenerate in places.

Four other similar experiments, while not entirely satisfactory, met with some success. In one of these the ovaries were transplanted to a male rat. The graft showed recognisable ovarian tissue in parts, but had undergone very considerable degeneration.

A number of experiments were also performed in which ovaries from one rat were grafted under the skin on the anterior abdominal wall of another rat. In three such cases some success was obtained, but a larger number of grafts was absorbed than when the implantation was intraperitoneal.

It will be observed from the foregoing account of our experiments that it is possible to excise and graft ovaries in such a way that in many cases the grafts exhibit the characteristic histological features of ovarian tissue. The germinal epithelium had, however, always become absorbed in our experiments. In other cases a certain amount of degenerative change took place, only certain elements of the tissue being recognisable after the lapse of several months; thus the stroma might present its normal appearance

while the follicles had disappeared, or the greater part of the graft might be composed of luteal tissue alone.

It will further be seen that the cases of transplantation classed as successful are fewer in heteroplastic than in homoplastic implantation. Of our two successful heteroplasts, one was a graft into a rat of the same litter, while the other was possibly but not certainly a similar case.

The maintenance of the histological characters in successful grafts points to retention by them of function, and further evidence of their functional integrity is derived from the fact that the constituents of the graft varied according to the period in the reproductive cycle at which the animal was killed. At the commencement of the breeding season large follicles were found in the graft; at a later period corpora lutea were present. It is to be presumed, therefore, that the grafts passed through the same phases of functional activity as normal ovaries.

Condition of Uterus after Ovarian Transplantation.

We examined the histological condition of the uterus in those cases where the ovaries had been removed and transplanted to another position in the body. The appearance of the uterus was found to bear a relation to the microscopic structure of the graft. If the latter had retained unaltered, or with little alteration, the typical characters of ovarian tissue, the uterus was found undegenerated; thus in Experiment 8 of our series of homoplasts (p. 596), in which the ovaries had been transplanted for six months, the uterus was normal. If, however, the graft had failed to "take," the uterus exhibited undoubted evidence of degeneration. Where the graft had been successful, on examining it and the uterus post mortem we found that each organ had the appearance appropriate to the time of year and stage of reproductive cycle at which the animal was killed. Thus in one case where the graft had met with some measure of success, and the animal was killed at the beginning of the breeding season, the ovary contained large follicles and the uterus was in the condition which has been described as the recuperative stage of the œstrous cycle.

In the case of transplantation from rat to rat, uterine degeneration was found, as in homoplastic implantation, to be arrested by a successful graft.

General Conclusions.

In our previous paper (1905) we supplied evidence in support of the view that heat and menstruation are induced either directly or indirectly through the activity of an internal secretion or hormone arising in the ovaries, while we adduced further evidence that the corpus luteum provides a secretion which assists in the nourishment of the embryo during the first stages of pregnancy. In the present paper we show that the existence of ovarian tissue is an essential factor in normal uterine nutrition; and further, that the nature of the ovarian influence upon the uterus is chemical rather than nervous,

since the transplanted ovaries, while still maintaining their functions (at least in many cases), had lost their normal nervous connections. It is extremely probable, therefore, that the uterus is dependent for its proper nutrition upon substances secreted by the ovaries, not merely at the heat periods and during pregnancy, when they show their greatest activity, but throughout the whole of the œstrous cycle.

The expenses of the investigation were defrayed by grants from the Government Grant Committee and from the Carnegie Trust.

POSTSCRIPT.

Since this paper was communicated, CARMICHAEL has published a paper on "The Possibilities of Ovarian Grafting in the Human Subject." He describes numerous experiments on homoplastic transplantation in rabbits, the majority of which were successful in parts. CARMICHAEL is of opinion that in larger animals, and in the human subject, the ovary when transplanted is unlikely to retain its complete functional activities owing to partial degeneration, although it is probable that portions of the graft may be got to survive.

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DESCRIPTION OF THE PLATES.

The figures were drawn by Mr RICHARD MUIR, of the Pathological Department, University of Edinburgh.

PLATE I.

FIG. 1. Grafted ovary from a case of homoplastic implantation, showing normal Graafian follicles with membrana granulosa, a small follicle with ovum, a degenerate follicle without membrana granulosa, and cysts lined by stratified squamous epithelium. The cysts are not improbably derived from other follicles. The graft was allowed to remain for two and a quarter months, and the rat was killed before the commencement of the normal breeding season. × 40 diam.

Fig. 2. Homoplast showing follicles, an ovum, and corpora lutea. The graft was left for two months, and the rat was killed during the breeding season. × 80 diam.

Fig. 3. Heteroplast showing a highly vascular corpus luteum. Graft left for three and a quarter months. × 80 diam.

PLATE II.

Fig. 4. Heteroplast showing follicles with normal membrana granulosa, interstitial cells, etc. Graft left for one and a half months. × 120 diam.

Fig. 5. Transverse section of normal uterus of rat, showing glands, etc. × 40 diam.

Fig. 6. Transverse section of uterus of rat castrated six months previously. The lumen is small, the mucosal glands inconspicuous, the muscular wall thinned, and the fibrous tissue increased. × 40 diam.

Fig. 7. Transverse section of uterus of rat in which homoplastic implantation had been performed two months previously. The uterus is practically normal. × 40 diam.

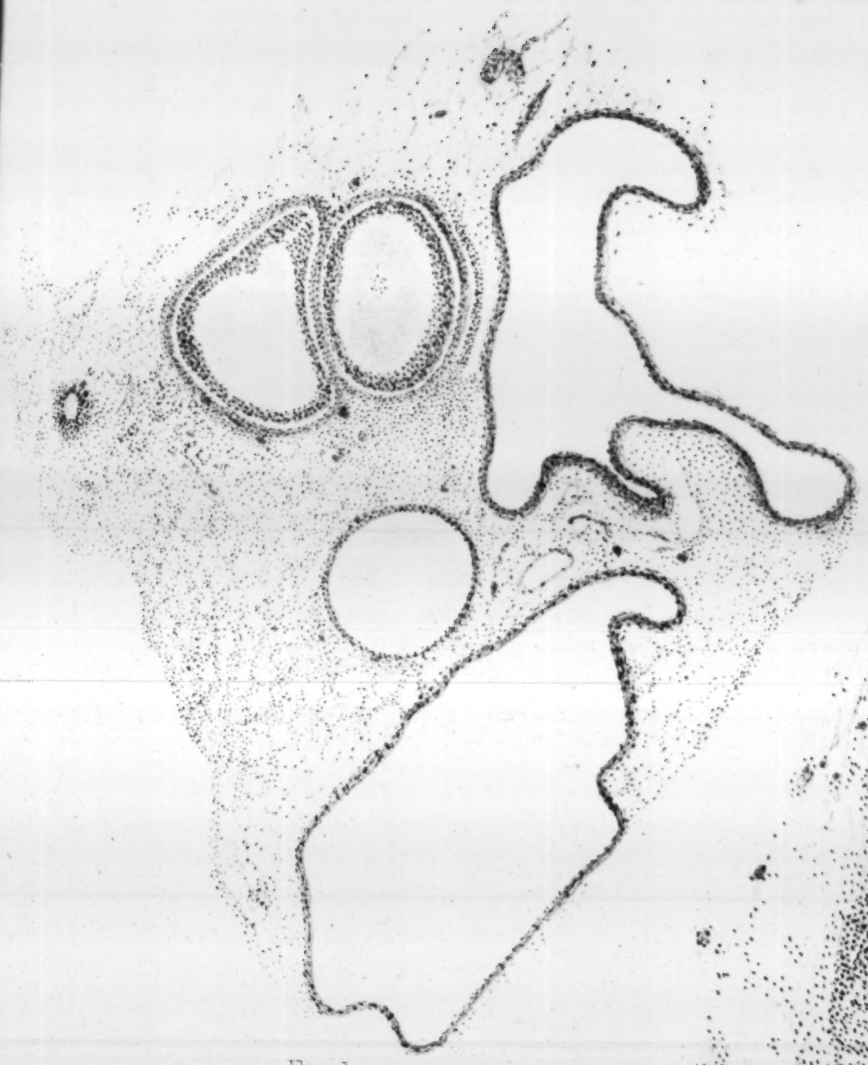

Fig 1

Fig 2.

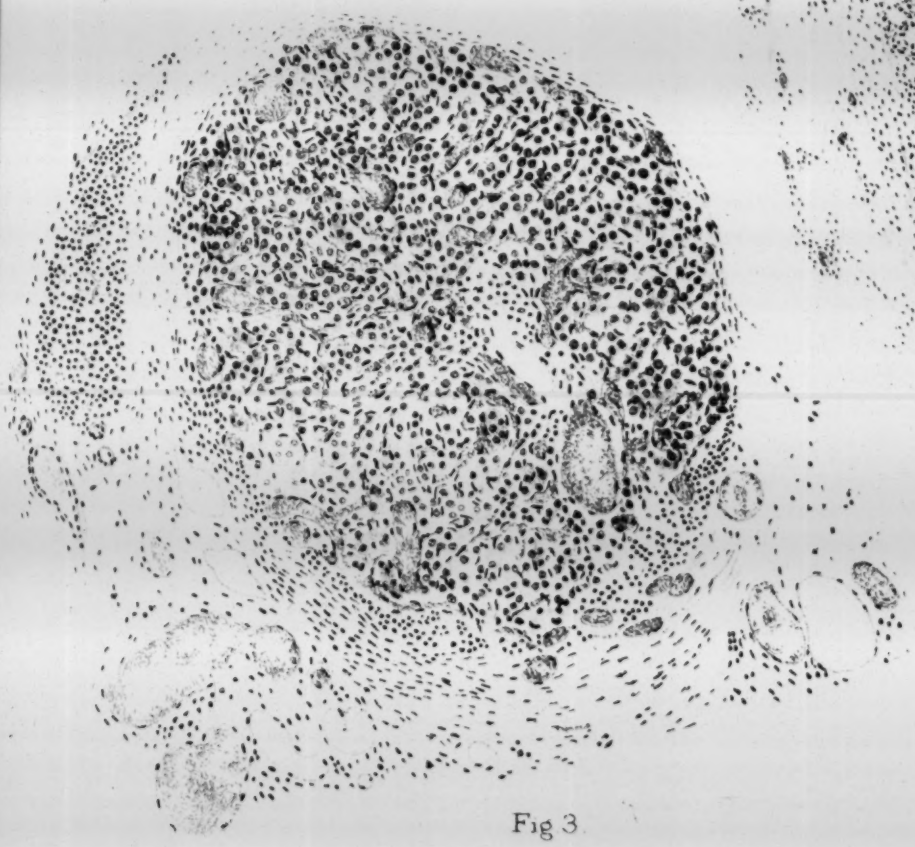

Fig 3.

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Fig. 4

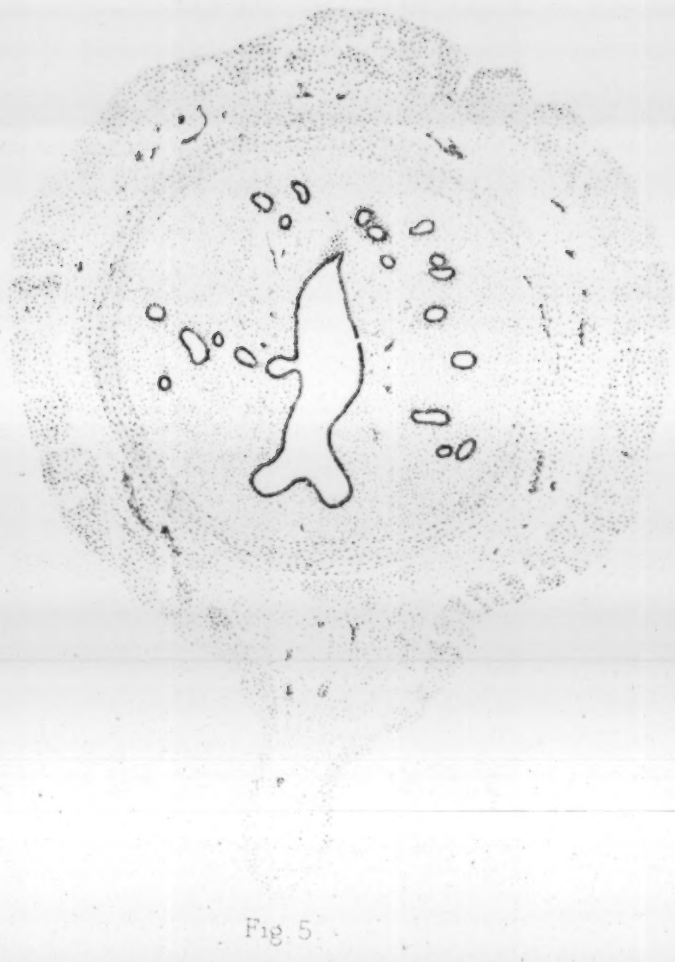

Fig. 5

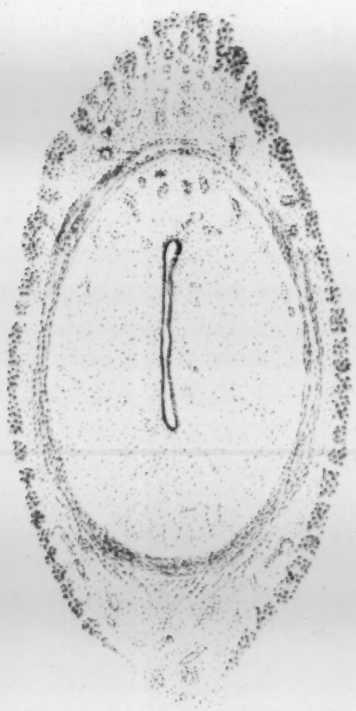

Fig. 6.

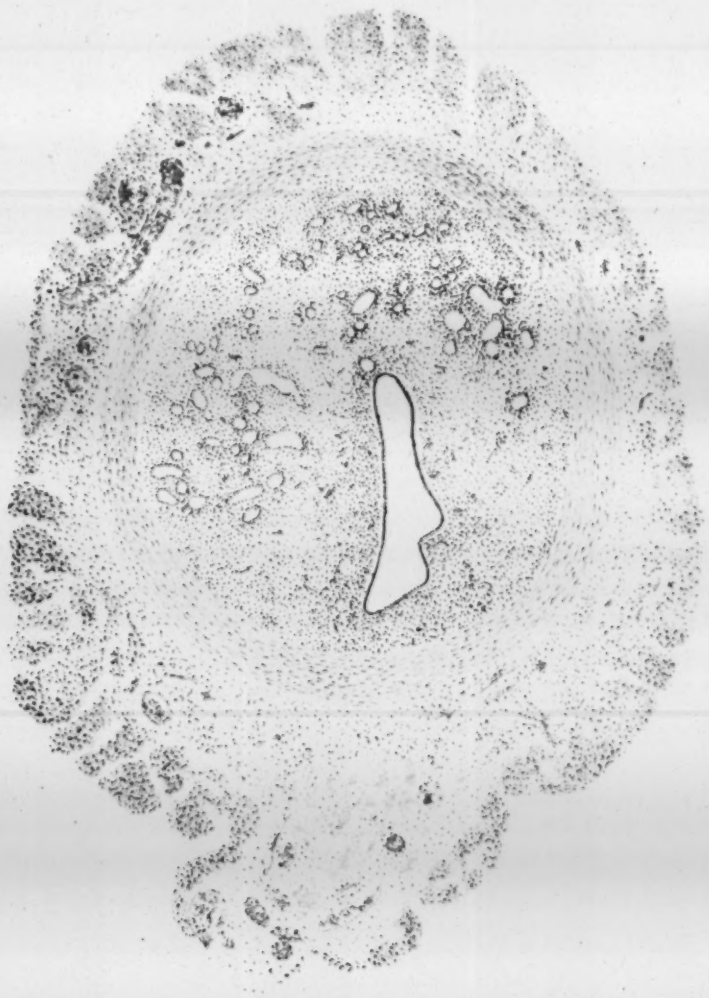

Fig. 7

Hunt. lith. London

XXII.—The Geology of Ardrossan. By J. D. Falconer, M.A., D.Sc., F.G.S. (With Two Plates.)

(MS. received January 26, 1907. Read February 18, 1907. Issued separately May 9, 1907.)

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I. Introduction.

The town of Ardrossan is built largely upon the 15-feet beach * which to the north and south of the promontory is a well-marked terrace of sand and gravel, but on the promontory itself is represented by a rocky shelf rarely exceeding 12 feet in height. The promontory owes its origin to a great extent to the igneous rock of the Castlehill and the Inches, which has offered more resistance to marine denudation than the neighbouring sandstones. The railway to West Kilbride runs for some distance along the 50-feet beach, while the 100-feet beach is represented by an irregular accumulation of sand and gravel some distance inland.

The geology is interesting both on account of the variety of sedimentary and igneous rocks to be found within a small compass, and on account of the excellent exposures of faults of many different types which may be studied on the shore at low water. Of the latter, three are particularly interesting. The faults of late Palæozoic age which bound the Castlehill converge towards a centre of faulting in the vicinity of Dykesmains. The more northerly brings down the lava of the Castlehill against massive red sandstones whose stratigraphical position is about 400 feet above the cornstones; the more southerly truncates obliquely the margin of the Castlehill lava, and turns both it and the lower limestones on end at the Inches. The great sinuous N.W.–S.E. fault of the Inches, the Harbourback, and the Horse Island, probably of Tertiary age, is more a great lateral wrench or shatter-belt than an ordinary fault. There has been little vertical displacement, but, wherever exposed, it is characterised by a line of brecciation with small anastomosing dykes rising through the broken rock. At the Inches it cuts the Castlehill fault and shifts the outcrop of the upturned limestones 300 yards to the west.

* "The Geology of North Arran," *Mem. Geol. Sur.*, p. 140.

	I. North of Ayrshire.	II.* Stanley Burn, Whitecraigs, and Ardrossan Waterworks.	III. Burnfoot Bridge.	IV Harbourback.	V. Inches.	VI. Horse Island.
Carboniferous Limestone Series.	Volcanic series.				Ironstones, black shales, and thin coals.	
	Coals, ironstones, and limestones.	Limestones.			Limestones, sandstones, and shales.	Limestones, sandstones, and coaly shales.
	Volcanic series.	Lavas and ash.		Lavas.	Lavas and ash.	Lavas and ash.
		Thin sandstones and shales, frequently ashy.		Red ashy sandstones.		Red ashy sandstones.
				White sandstones and blue-green shales with calcareous nodules.		
	Cementstones and cornstones.	Whitecraigs limestone.		Hard, splintering calcareous sandstone.		
Calciferous Sandstone Series.				Massive white sandstone.		White sandstones with yellow concretions.
		Greenish marls.	False-bedded red and white sandstones with yellow calcareous concretions.	White sandstones with yellow concretions.		
			Red and white sandstones (much broken).			
		Sandy limestone.	Concretionary sandy limestone.			
Upper Old Red Sandstone.	Red and yellow sandstone.	Red and yellow sandstones, frequently mottled and pebbly.				

* Not shown on accompanying map, Plate I. (See Geol. Sur. Map, Sheet 22.)

II. Statigraphy.

The above table gives the general sequence of strata in the north of Ayrshire,* and correlates the various exposures in the neighbourhood of Ardrossan. It should be noted that the cornstones and cement-stones are here very imperfectly developed. The horizon is, however, well indicated either by the occurrence of sandy limestone and greenish marl, or by the presence of a false-bedded pebbly white sandstone with calcareous concretions, which is a well-marked member of the series at Ardrossan and the Horse Island. The volcanic series which at Whitecraigs is about 300 yards in thickness is barely half as thick at Ardrossan, while in the Horse Island the same series is compressed into less than 50 feet.† The Upper Old Red Sandstones are well exposed in the Stanley Burn from Whitelees to within 200 yards of the old quarry at Whitecraigs. They dip constantly up stream at a low angle, increasing towards the north, and it is probable that both they and the overlying volcanic series originally bent over an anticlinal axis striking N.W.–S.E. behind Ardrossan. The red sandstones formerly quarried in the town may thus be correlated with similar red sandstones at Blackhall. The thin concretionary limestone or cornstone 300 yards north of Burnfoot Bridge, which is here taken as the limit of the Old Red Sandstone, is occasionally exposed at low water after a heavy storm.

III. Petrography.

(*a*) *The Carboniferous Lavas and Tuffs.*

Two types of lavas may be distinguished.

(A) There are on the one hand the lenticular terminations of a few of the great basaltic flows which build the volcanic plateau to the north,‡ and which may be seen between tide-marks, upturned at the Inches and dipping out to sea at the Harbourback and the Horse Island. They are usually somewhat coarse in texture and much decomposed. (B) Below these at the Inches and the Castlehill only, not at the Harbourback, there occurs a columnar, fine-grained, and compact dark blue basalt, very vesicular on the margins, which is in every way similar to that which has risen along the margin of the large truncated neck in the Horse Island. It is evident that before the plateau lavas had yet covered the site of Ardrossan there were a number of small volcanic vents to the westward, through one of which, now in part in the Horse Island, a basalt rose which flowed eastwards to form the Castlehill. Since that time the Ardrossan neighbourhood has been much shattered by faulting, but with care it is still possible in this way to correlate the various igneous rocks.

Thin beds of ash, ashy sandstone, and clay are associated with the lenticular masses

* See also *Mem. Geol. Sur.*, Expl. of Sheet 22, p. 9.

† *Cf. Ancient Volcanoes of Great Britain*, vol. i. p. 393.

‡ *Ancient Volcanoes of Great Britain*, p. 368.

of lava at the Inches. At the Harbourback and the Horse Island there occurs a thin series of dark red ashy sandstones whose igneous constituents are probably to be referred to the volcanoes of the plateau. The smallest neck in the Horse Island is partially filled with this broken ashy sandstone; the others are full of a dull green or reddish agglomerate composed of blocks of ashy sandstone and shales, masses of earlier basic lavas and ash, occasional fragments of plutonic igneous rocks, and, more rarely, portions of charred wood impregnated with pyrites, the whole bound together by a matrix of sandy ash. A central dip may in places be observed, and at the S.E. end of the east islet the agglomerate may be seen lying conformably upon a hard white sandstone. This agglomerate, and the Castlehill and Inches lava, probably occupy the position of the red ashy sandstones elsewhere.

Under the microscope the lavas (A) are basalts of a more felspathic type than the Castlehill and Inches lava (B). Their ground-mass is composed of small lath-shaped felspars, arranged as a rule in rude fluxion streams. They belong mostly to andesine and labradorite, and are commonly clear and little decomposed. Augite granules have been abundant, but are now as a rule replaced by calcite. (See Pl. II., fig. 1.) Some flows have originally possessed large porphyritic felspar crystals which are now replaced by calcite and chalcedony. Large irregular phenocrysts of olivine are characteristic of these lavas at the Inches; they are never fresh, but always replaced by a mass of serpentine and calcite. The ash associated with these rocks consists of small lapilli of the same felspathic lavas and fragments of various clastic rocks, bound together by a fine-grained, decomposed, and much calcified volcanic dust.

The lava (B) is much finer-grained and less felspathic than the representatives of the plateau basalts described above. Samples from the interior and margins vary somewhat in texture, the former being slightly coarser and less markedly fluidal than the latter. The marginal portions are frequently also minutely vesicular and much brecciated. Small crystals of olivine in idiomorphic, pyramidal, or rectangular sections, or in irregular corroded forms, are the only phenocrysts, and give the rock a characteristic appearance under the microscope. Occasionally an intergrowth of olivine and augite may form a large irregular porphyritic mass. In the groundmass the felspar microlites, which vary from oligoclase to labradorite, are as a rule subordinate in quantity to the augite grains, which are frequently idiomorphic. There is a little apatite and much black magnetite dust, and in places a small quantity of brown glassy base. (See Pl. II., fig. 2.) The basalt in the neck in the Horse Island has similar microscopical characters.

The most interesting feature about this rock, however, is the number and variety of xenoliths and xenocrysts which it contains, and the effect of the caustic action of the basic magma upon these. The brecciated margins of the flow contain abundant fragments of earlier felspathic lavas very similar in character to the lavas (A), as well as fragments of shale, limestone, and microcline-bearing sandstone. These have probably been caught up during the flow, and have as a rule suffered little or no change beyond induration or recrystallisation. The interior of the flow, however, contains numerous

angular and subangular fragments of a holocrystalline igneous rock which, from their rusty brown or greenish colour, are particularly conspicuous upon the wave-swept surface of the Inches lava. These under the microscope are found to be fragments of dunite and augite-peridotite, composed entirely of rounded grains of olivine with occasional irregular interstitial crystals of augite and pictotite.* They appear to have suffered little or no corrosion by the basic magma. That they are not, however, of the nature of olivine nodules but are real xenoliths, is evident both from their general angular shape and from the occasional presence of a zone of brown glass surrounding them. Xenoliths of granite and of quartz-orthoclase pegmatite are also common, and some slight corrosive action has occasionally taken place around these especially in the neighbourhood of the quartz. The most interesting and intense action of the basic magma is, however, to be observed round isolated xenocrysts of quartz and felspar, which sometimes reach a considerable size. The felspar xenocrysts belong commonly to acid oligoclase, and have suffered the usual regular penetration by the basic magma along the cracks and cleavages. The quartz xenocrysts, if small, are surrounded by a ring of tiny augite crystals, or by an outer zone of augites and an inner of brown glass. If the quartz crystals are large, however, and if they have suffered much corrosion, the early formed outer ring of augites may again be absorbed and in the broad zone of glass there may develop skeletal isotropic microlites of felspar, which later become radiating groups of well-defined and often repeatedly twinned crystals of acid plagioclase, most commonly of oligoclase.† (See Pl. II., fig. 3.)

(*b*) *The Carboniferous Intrusive Rocks.*

1. *The Castle Craigs Picrite.*

This rock, which may be termed picrite from its most interesting modification, in reality passes regularly upwards from picrite to hornblende dolerite along the whole length of the sill (fig. 1).

The lowest layer (1) in contact with a white sandstone is a fairly coarse-grained greenish rock, flecked with pink and white. Above this is a coarse-grained dark-green rock (2), in places rendered friable through exposure, which makes up more than half of the intrusion. Traced upwards, this rock becomes somewhat finer grained; spots and streaks of pink felspar begin to appear in it, and these become more and more abundant until the rock itself assumes a pinkish colour (3). At the same time coarse red felspathic knots become frequent, the usual central cavity being filled with calcite or analcime. The upper portion of the sill (4) is very fine-grained and pseudo-laminated, showing an alternation of narrow reddish and greenish bands parallel with the upper surface of the sill and crossed occasionally by tiny pink felspathic veins. This fluidal banding becomes more and more pronounced as the margin is approached.

* *Cf.* "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Sur.*, p. 69.
† *Cf. Tertiary Igneous Rocks of Skye*, pp. 361, 481; *Geology of North Arran*, pp. 114, 116.

Portions of baked shale may be found here and there still adhering to the upper surface of the dolerite.

Microscopically, a corresponding variation may be traced in the mineral composition. In the lowest layer (1) large olivines, more or less idiomorphic and entirely replaced by calcite, make up rather more than half the rock; the remainder is composed of small idiomorphic chloritised augites, ragged flakes of biotite, and numerous lath-shaped crystals of basic labradorite, usually turbid and opaque. The interstices are filled with cloudy analcime which here, as in other portions of the rock, may possibly be in part of primary origin. In the coarse dark-green rock (2) overlying this, felspar is almost entirely wanting, and olivine, purple augite, and brown hornblende, with a little biotite, apatite, and iron-ore, are the principal constituents. The rock is, in fact, a very

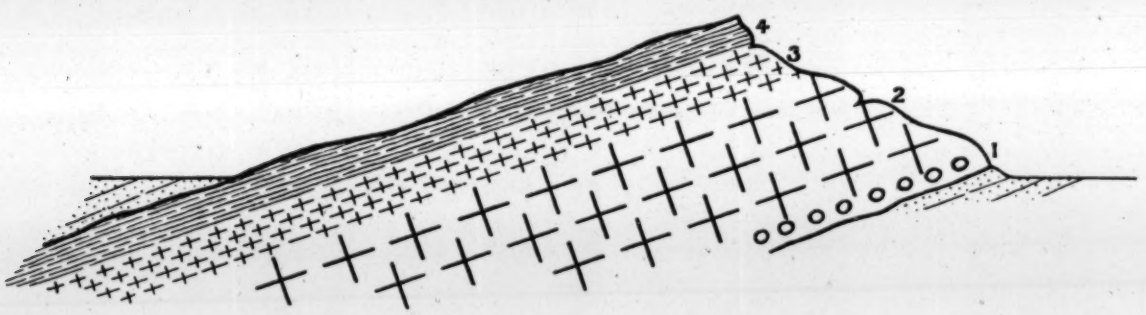


FIG. 1.—Diagrammatic section of Castle Craigs picrite.
1. Olivine-felspar rock at lower margin; 2. picrite; 3. hornblende dolerite; 4. fine-grained banded dolerite.

typical hornblende picrite.* (Pl. II., figs. 5 and 6.) The felspar when recognisable belongs to bytownite or anorthite, but is usually much decomposed. The olivines are large and frequently idiomorphic; the augites have also a tendency to idiomorphism, and are usually surrounded by plates of brown hornblende which, when a little interstitial felspar is present, usually shows good outlines. Sometimes the amount of hornblende and augite seems to increase at the expense of the olivine, and large irregular plates of hornblende are distributed throughout the section, usually enclosing some idiomorphic augites pœcilitically. The occasional spotted appearance of the rock is due to the presence of small aggregates of felspar, much decomposed and stained with iron ore. As the felspar becomes more abundant and the rock becomes finer-grained and assumes a pinkish tint (3), idiomorphic augite remains the most important ferro-magnesian constituent. Olivine is much scattered, and hornblende and biotite build small crystals or fringe the augites. The felspars are lath-shaped and belong mostly to labradorite; they are usually somewhat turbid and decomposed, and are rarely enclosed in the augite in an ophitic manner. Apatite and iron ores are present in small quantity, and interstitial analcime is sometimes abundant. The picrite has, in fact, passed into a hornblende-dolerite. The upper portion of the sill (4), whose striated character is due to the alternation of more and less felspathic bands, is merely a fine-

* *Cf. Quart. Journ. Geol. Soc.*, xxxvii. p. 137; xxxix., p. 254.

grained dolerite with practically no olivine, and with the small idiomorphic augite and hornblende crystals and the tiny laths of felspar set in an ill-defined felspathic matrix, which is largely replaced by analcime and calcite. (Pl. II., fig. 4.) At the upper contact the rock is exceedingly fine-grained, much decomposed, and full of calcite. There is no trace of fluxion structures even in the most minutely banded portions of the sill.

This rock, then, affords an excellent example of the differentiation of one and the same magma into a lower basic and an upper felspathic portion. The composition of the rock at the lower contact does not materially affect the case, because although there is there a recognisable increase in the amount of felspar, the rock as a whole is much more nearly allied to the picrite than to the dolerite. There is, in fact, no question here of differentiation into a central basic and marginal acid portions, for the transition from picrite to dolerite can be traced in one direction only; moreover, the differentiation to which this is due must have taken place in the reservoir entirely before intrusion. It is evident from the absence of fluidal structures in the finer-grained banded upper portion that crystallisation did not begin until the whole mass was at rest. The striation cannot, therefore, be due to the segregation of the various minerals into layers during intrusion; it must rather be assigned to a heterogeneity in the magma itself at the time of intrusion. In this respect the Castle Craigs picrite presents considerable analogy to the banded peridotites and gabbros of Skye,* and differs from the Blackburn and Barnton picrites† in which the differentiation which has given rise to similar types took place entirely after intrusion. Further, from the fact that this sill, like some of the dykes of banded gabbro in Skye,‡ is asymmetrical with respect to the texture of its upper and lower margins, we may conclude that there has been here also more than one period of intrusion, and that the upper fine-grained and banded portion is somewhat younger than the coarse-grained lower portion. That the one has very closely followed the other from the same source is evident, however, from the very gradual manner in which the dolerite everywhere passes down into the picrite.

2. *The Baths Gate Dolerite.*

This intrusive rock is pale gray or green in colour, and has probably been originally a coarse-grained ophitic olivine dolerite. It is now, however, entirely decomposed and more or less changed into a substance analogous to the white trap of the coalfields. It has evidently been intruded into the midst of thinly-bedded carbonaceous shales, sandstones, and ironstones; and streaks and bands of these, especially of the sandstone, are to be found traversing the decomposed rock, like veins of a later origin. These ribs of sandstone, on fracture, are frequently black and lustrous, and under the microscope are composed of scattered rounded quartz grains and black carbonaceous knots set in a matrix of cryptocrystalline chalcedony. Evidently the sandstone has been partially

* *Tertiary Igneous Rocks of Skye*, pp. 75, 90.
† *Ancient Volcanoes of Great Britain*, vol. i. pp. 419, 450.
‡ *Tertiary Igneous Rocks of Skye*, p. 118.

fused, and the rounded quartz grains are the corroded remnants of the original clastic fragments.*

(*c*) *The Tertiary Dykes.*

The sinuous dyke at the Bath House is remarkable in having the friable coarse-grained interior sharply marked off from broad marginal bands which, being more compact, have offered greater resistance to decomposition. The interior is a coarse-grained olivine dolerite, while the margins are somewhat more acid with porphyritic groups of felspar laths set in a basaltic groundmass. At the Inches, the Harbourback, and the Horse Island numerous dykes rise along the line of the great wrench fault. On the accompanying map these are shown as one; but in reality there are always two, and there may be as many as four, small dykes ramifying through the broken rock (fig. 2). Petrographi-

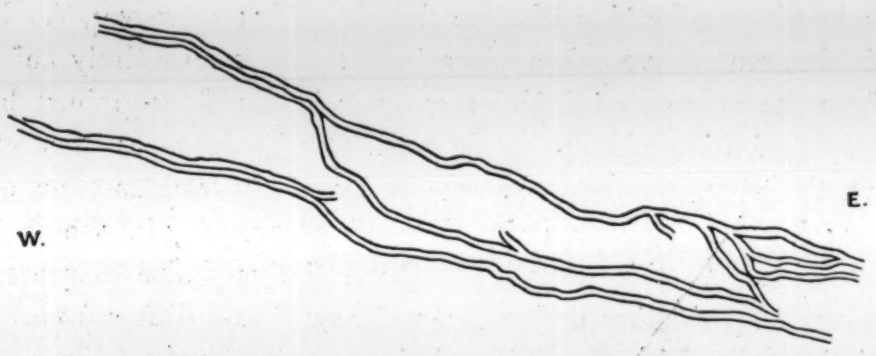


FIG. 2.—Plan of Dykes in the shatter-belt at the Harbourback. Scale $\frac{1}{1250}$.

cally, these are basalts of two types: a fine-grained micro-ophitic olivine basalt, and a somewhat more acid type with phenocrysts of felspar in a groundmass of felspar microlites and augite and magnetite grains. Dykes of similar material running parallel with the fault line are found piercing the Castle Craigs picrite and sandstones of the Horse Island. A small dolerite dyke in the east islet, running at right angles to the shatter-belt, is noteworthy in possessing fine-grained sheaths to the coarse-grained irregular polygonal masses into which it is broken up, the sheaths being usually provided with a median suture.† Various dykes and thin intrusive sheets are found in the vicinity of the cornstone at Burnfoot Bridge; these vary from olivine dolerites to felspar basalts, and differ somewhat in texture and in the relative proportions of augite and felspar.

* See *The Tertiary Igneous Rocks of Skye*, p. 246.

† *Cf.* "The Geology of Cowal," *Mem. Geol. Sur.*, p. 144.

IV.

DESCRIPTION OF PLATE II.

Fig. 1. Basalt, Harbourback. The tiny lath-shaped felspars are arranged in rude fluxion streams. The dark-coloured minerals are aggregated into heaps, the augite being almost entirely decomposed and replaced by calcite and chlorite. × 20.

Fig. 2. Olivine-basalt, Castlehill. The small phenocrysts of olivine are much serpentinised, and set in a ground-mass of felspar microlites and augite and magnetite grains. × 20.

Fig. 3. A much corroded xenocryst of quartz from the Inches basalt, with groups of oligoclase microlites formed as the result of the acidification of the basic magma. × 20.

Fig. 4. Hornblende dolerite, upper part of Castle Craigs. The small crystals of augite and hornblende are more or less idiomorphic, the former much decomposed. The felspars are fairly fresh, and the interstices are filled with analcime and calcite. × 40.

Fig. 5. Hornblende picrite, Castle Craigs. Crystals of olivine and augite are enclosed in large plates of hornblende. A little decomposed felspar appears in the upper part of the section. × 30.

Fig. 6. Hornblende picrite, Castle Craigs. Olivine and hornblende are the principal constituents. Irregular crystals of augite are enclosed in the hornblende, and a little cloudy felspar occurs interstitially. × 30.

NORTH BAY

ARDROSSAN

Harbour

SOUTH BAY

Fort

G. & S. W. R.

Stanley

Burntoot Bridge

Parkhouse Reservoir

Quarry

Stanley Burn

Castle Hill

EGLINTON DOCK

OLD DOCK

SOUTH CRESCENT

South Beach

Castle Craigs

HORSE ISLE

Scale ½ Mile

Present Beach.

Raised Beach.

d^2 Carboniferous Limestone Series

d^1 Calciferous Sandstone Series

C^3 Upper Old Red Sandstone with Cornstone at top.

Fd^1 Lavas } VOLCANIC

Tsd^1 Ash. } VOLCANIC

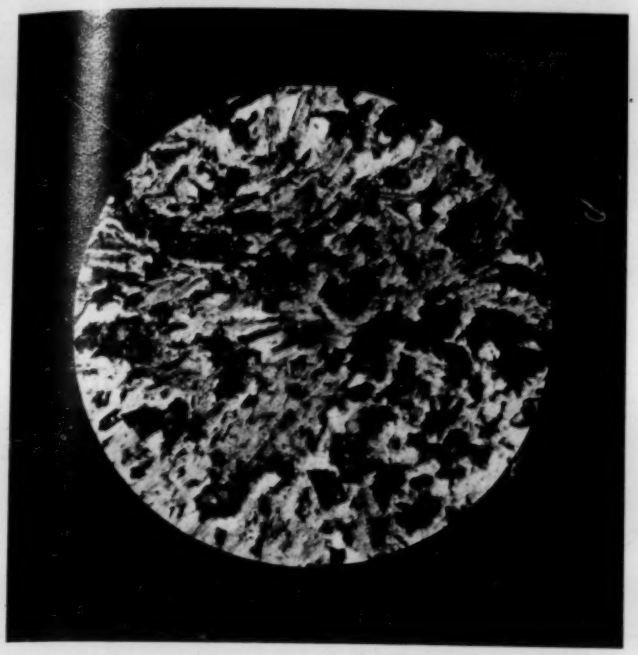
Basalt etc. } INTRUSIVE (Dykes & Sills)

Dip of strata. (amount in degrees)

McFarlane & Erskine, Lith. Edin.

FALCONER: GEOLOGY OF ARDROSSAN.

PLATE II.



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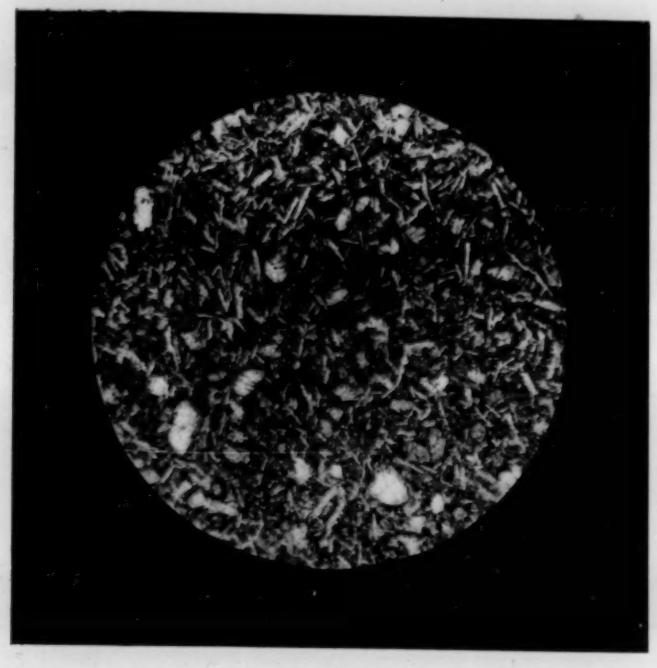

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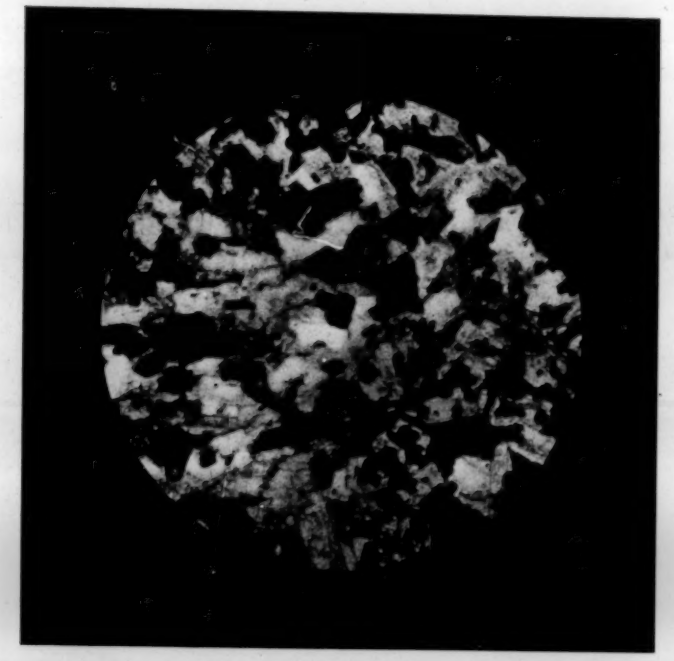

4

XXIII.—The Development of the Anterior Mesoderm, and Paired Fins with their Nerves, in Lepidosiren and Protopterus.

By **W. E. Agar**, B.A., Junior Assistant in Zoology at Glasgow University. *Communicated by* Professor J. Graham Kerr. (With a Plate.)

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I. The Head Mesoderm.*

In a *Lepidosiren* embryo of stage 20 (Graham Kerr) the mesoderm stretches continuously through the head and trunk regions. In the trunk the dorsal mesoderm is segmented into myotomes, but the segmentation stops short some distance behind the auditory vesicle, leaving *unsegmented* mesoderm in front of this. In both head and trunk the lateral plate mesoderm is still connected with the dorsal, myotomic or somatic portion.

In the head, the mesoderm reaches up on each side to the front end of the optic vesicle. It consists of (1) compact mesoderm, composed of a dorsal, somatic portion, continuous ventro-laterally with the lateral plate, and (2) a loose mesenchyme between the somatic mesoderm and the ectoderm (text figure 1). This mesenchyme is being formed by the breaking up of the compact mesoderm, as can be seen by following up successive stages, when it becomes apparent that the former is increasing at the expense of the latter.

At this stage there are three solid gill outgrowths from the solid pharynx on each side. They are connected by a ridge,—branchial ridge (text figure 1). These gill outgrowths break through the intermediate mesoderm connecting the somatic and lateral plate mesoderm (text figure 1), so that the latter, being entirely ventral to the outgrowths, is uninterrupted. The intermediate mesoderm connecting the somatic mesoderm and lateral plate in front of the first outgrowth corresponds with the mandibular cavity of Balfour and van Wijhe (though it is, as a matter of fact, a solid meso-

* The material for this investigation was that in possession of Professor J. Graham Kerr, who kindly allowed me to make use of it for the purpose, and in whose laboratory the work has been done.

This thesis formed part of one of the essays successful in gaining the Walsingham Medal of Cambridge University in 1906.

thelium), and the connection left between the first and second outgrowths corresponds to the hyoidean cavity (also a solid mesothelium). Behind this there is another section of mesothelium cut off between the second and third outgrowths, and behind this the lateral plate and dorsal mesoderm are connected by a continuous sheet of mesothelium.

There is no trace of segmentation of the dorsal or somatic mesoderm of the head at this or any other stage, and there is no reason to regard the portions of mesothelium cut off between the gill outgrowths as having any segmental value. It may be specially noted that there is no indication of a premandibular cavity. As will be seen later on, however, in discussing the development of the eye and mandibular muscles, there is some reason to believe that regions corresponding with the somatic portions of the first three head somites of BALFOUR and VAN WIJHE (premandibular, mandibular, and hyoidean) are differentiated from one another.

In the trunk, at this stage, the lateral plate is unsplit. In the head, the somato-

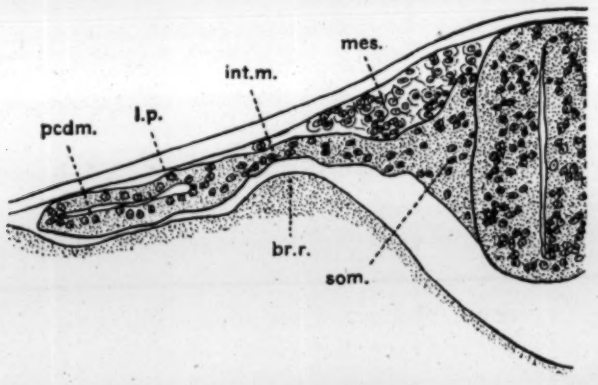

FIG. 1.—*Lepidosiren*, stage 20, transverse section between the first and second gill outgrowths. *br.r.*, branchial ridge; *int.m.*, intermediate mesoderm; *l.p.*, lateral plate; *mes.*, mesenchyme; *pcdm.*, cavity in lateral plate representing first rudiment of pericardial cavity; *som.*, somatic or myotomic head mesoderm.

pleural layer of mesoderm has separated from the splanchnopleural in the region ventral to the first two gill outgrowths, forming the first, paired, rudiments of the pericardium. The lateral plates of the two sides are still wide apart throughout their whole length, owing to the fact that the pharynx and "stomodæum" have not yet become folded off from the yolk sac, over the surface of which the lateral plates are spread out.

At stage 23+ the lateral plate in the trunk has separated from the myotomes. As before, it stretches up without a break from the trunk into the head, but the series of trunk myotomes is now sharply marked off from the somatic head mesoderm, the latter having almost completely broken up into loose mesenchyme. The front end of the trunk series is a short distance behind the auditory vesicle,—the actual distance varies considerably, but is usually rather more than the length of one myotome.

At the last stage we saw that the three gill outgrowths first formed cut off between them portions of the mesothelium connecting the lateral plate and somatic mesoderm. When the posterior gill outgrowths are formed, they do not, however, cut off similar portions of mesothelium, this having now entirely resolved itself into mesenchyme,

leaving the lateral plate as the only remaining epithelial mesoderm in the head. This lies entirely ventral to the branchial ridge, and so is uninterrupted by the gill outgrowths. The mesothelium included in the first three visceral arches has also become mesenchymatous. The lateral plates now meet in the extreme front end of the head in the middle line, below the "stomodæum," which has now been folded off from the underlying yolk sac.

In the trunk, the pronephrocœles have appeared opposite the pronephrostomes, but the mesoderm ventral to this is unsplit. In the head the paired rudiments of the pericardial cavities have met in the middle line in front. The cavity extends backwards for some distance on each side into the diverging lateral plates.

From this point it will be convenient to consider the development of the different parts separately.

Ia. Segmentation and Musculature of Head.

As already mentioned, there is no segmentation of the somatic portion of the head mesoderm. The development of the muscles derived from the three anterior head somites of Elasmobranchs is as follows in *Lepidosiren* and *Protopterus*.

At about stage 30 we find the future eye muscles and the temporal muscle represented by dense condensations of heavily yoked mesenchyme (text figures 2, 3, 4). The condensation round the optic vesicle (text figure 2) is continued backwards as a well-defined narrow strand, which passes into the larger mass forming the rudiment of the temporal muscle (text figure 3), joining it on its medio-dorsal border. This strand of mesenchyme can be traced further back still (text figure 4), curving in somewhat towards the middle line, and breaking up posteriorly into the general mesenchyme. This description applies to both genera.

This may be interpreted as showing that the mesenchyme concentrated round the eyeball derives its source partly from a concentration in the orbital region (corresponding to the premandibular somite), partly from the same source as the temporal muscle (mandibular somite), and partly from further back still. To be brought completely into line with the development in Elasmobranchs, etc., the posterior end of the mesenchyme strand should come from the same "somite" as the hyoidean muscles. No connection could be traced, however, between the mesenchyme in the hyoid arch and this strand, which in fact does not reach so far back.

The anterior portion of the eye muscle rudiment (premandibular and mandibular portions) can be traced back to a portion of the somatic head mesoderm lying between the first gill outgrowth and the optic vesicle, which does not completely break up into loose mesenchyme. A similar compact mass of mesoderm is apparently not left above the second visceral arch when the mesoderm in this becomes mesenchymatous.

It is impossible to say from which source the different eye muscles are derived, as

the whole mesenchyme from which they arise becomes merged into a continuous mass before the individual muscles are differentiated. The posterior extension of the eye muscle rudiment disappears by shortening up from behind, about stage 32.

This greatly modified mode of development of the eye muscles may probably be partly referred to the reduced condition of these organs in the adult, but to a greater extent to the large amount of yolk in the tissues.

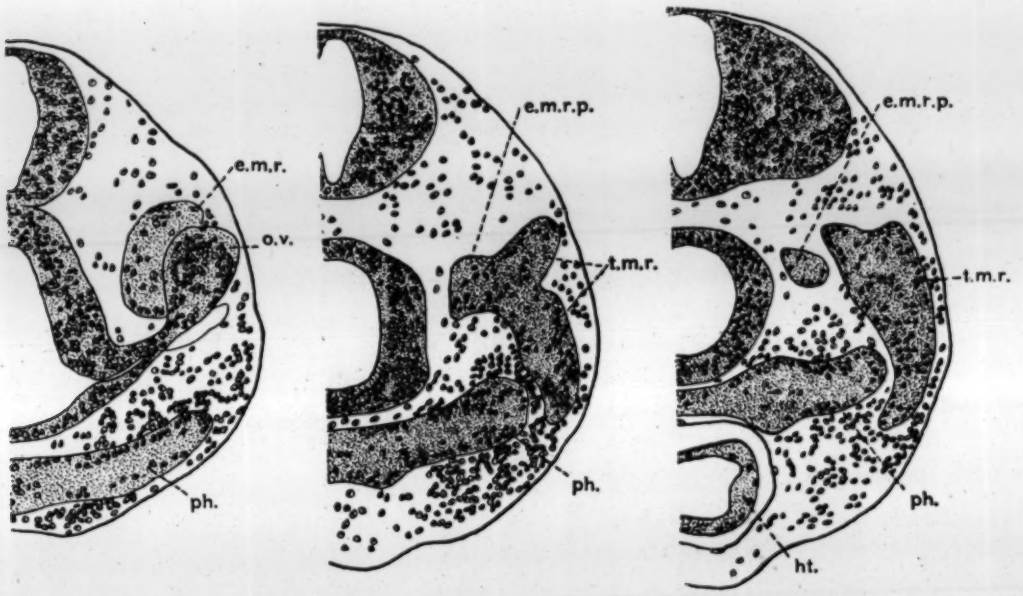

FIG. 2. FIG. 3. FIG. 4.

FIGS. 2, 3, 4.—Three sections from the same individual of *Protopterus*, stage 30, separated by spaces of 50μ. Fig. 2 is the most anterior. *e.m.r.*, eye muscle rudiment; *e.m.r.p.*, backward extension of this rudiment; *ht.*, heart; *o.v.*, optic vesicle; *ph.*, pharynx; *t.m.r.*, rudiment of temporal muscle.

As regards the metotic head "somites" of VAN WIJHE (5–9 VAN WIJHE, 4–9 many authors), two views are held:—

1. That they belong to the head proper, their splanchnic portions giving rise to the muscles of the branchial arches, the occipital nerves representing their somatic motor nerves, and their splanchnic, motor and sensory nerves being "collected" into the vagus (VAN WIJHE, Miss PLATT (table, p. 454), KOLTZOFF, JOHNSTON, etc.).

2. That they properly belong to a part of the trunk which has only lately become included in the hinder part of the head, and the mesoderm included in the visceral arches, though actually ventral to them (the metotic myotomes), belongs morphologically to the region in front of them. There is on this view a sharp break between the mesoderm of the head proper and these metotic or occipital myotomes, marking two genetically distinct parts of the head (spinal and pre-spinal, FRORIEP; cœnogenetic and palingenetic, GEGENBAUR; neo- and paleo-cranium, FÜRBRINGER). The posterior of these two regions (occipital myotomes) is regarded as having now come secondarily to

overlap the posterior part of the anterior one (branchial region). The occipital nerves belong, of course, to the occipital myotomes (cœnogenetic), and the vagus, which is formed by the coalescence at their proximal ends of the splanchnic fibres of the segmental nerves belonging to the posterior palingenetic head segments (of which only the splanchnic or branchial portions now remain), as belonging to the head proper.

This view has been maintained by GEGENBAUR, FRORIEP, FÜRBRINGER, BRAUS, etc.

Except for the fact that the posterior gill clefts are formed ventral to the occipital myotomes, and in *Scyllium* and *Pristiurus*, according to VAN WIJHE, the third visceral arch includes a portion of the lateral plate mesoderm while this is still in connection with the myotomes—*i.e.* before relative shifting is likely to have taken place ontogenetically—the preponderance of evidence seems to be in favour of the second view. The origin of the mesoderm of the branchial arches—whether from the same segments as the myotomes under which they are situated or not—is obviously of the greatest importance in deciding this question.

The facts in *Lepidosiren* and *Protopterus* are as follows:—As already mentioned, the segmented trunk mesoderm (occipital myotomes) stops short some distance behind the auditory vesicle.

The first gill outgrowth is pro-otic.

The second gill outgrowth is partly pro-otic, partly hypotic.

The third gill outgrowth is at first metotic, but, by backward extension of the auditory vesicle, very soon comes to be hypotic.

The fourth, fifth, and sixth outgrowths are metotic.

The visceral arches are constituted as follows:—

One and two include mesothelium connecting lateral plate with unsegmented pro-otic mesoderm.

Three includes mesothelium connecting lateral plate with unsegmented hypotic mesoderm.

Four includes mesothelium connecting lateral plate with unsegmented metotic (subsequently hypotic) mesoderm.

Five, six, and seven are formed after connection between the lateral plate and somatic mesoderm is broken through, and include only loose mesenchyme. They are formed in the region of the occipital myotomes (x, y, z).

Owing to the fact that these last visceral arches include loose mesenchyme only, it is not necessary to suppose that they belong genetically to the myotomes below which they are situated.

Lepidosiren and *Protopterus* therefore give no embryological evidence in favour of the first of the alternative views as to the nature of VAN WIJHE'S metotic head somites. Even in such cases as Scyllium and Pristiurus, where the third gill outgrowth cuts off lateral plate mesothelium still in connection with an occipital myotome, it is not necessary to suppose that the two structures originally belonged to the same segment. That lateral plate structures may in ontogeny appear under, and attached to, somatic

mesoderm belonging to a different region to that which their phylogenetic history would lead us to expect, is shown by the great forward displacement of the pericardium in embryos with much yolk, as in *Lepidosiren* and *Protopterus*. The cavity of the pericardium here develops at the extreme front end of the head, under the "stomodæum," while the lateral plate in which it appears is still attached to the somatic mesoderm.

On the other hand, *Lepidosiren* and *Protopterus* do not furnish the evidence in favour of a genetic distinction between a palingenetic and cœnogenetic somatic head mesoderm which is shown by many Elasmobranchs, in which the occipital myotomes migrate forwards during ontogeny, the anterior ones successively atrophying (BRAUS). The occipital myotomes retain their original position (relative to the vagus) throughout development.

The essential facts about the segmentation of the head in *Ceratodus*, according to GREGORY, are the following:—The head mesoderm is at an early stage continuous with the trunk mesoderm. At first unsegmented, it later becomes divided up, from behind forwards, into four (pro-otic) segments. These correspond to the first four somites of VAN WIJHE. The posterior segment is marked off by constrictions approximately over the first and second gill pouches. These constrictions appear while the head mesoderm is still connected with the trunk, so that the head and trunk segmentation are at this stage continuous. All four somites have cavities.

The fourth somite "soon loses its independence."

The third is the hyoidean somite. It has a cavity, lined externally by epithelial walls, its inner boundary being mesenchyme. It wanders forward internal to the second somite, but the material did not allow of its fate being traced further.

The second is the mandibular somite. It has a cavity like that of the third, but continuous with the cavity in the mandibular arch. It sends forward a process on to the dorsal edge of the eyeball, similar to that from which develops the obliquus superior in Elasmobranchs.

The first is the premandibular somite. The cavities on each side have epithelial walls, and are connected by a solid strand across the middle line. It gives rise to outgrowths, from which presumably the oculomotorius muscles develop.

As regards the fourth "somite," there seems no real reason for supposing it to have the value of a single somite. It would better be described simply as a mass of somatic mesoderm filling up the space between the hyoidean somite and the first occipital myotome.

Adding our knowledge of the constitution of the head mesoderm in the Dipnoi to our previous knowledge of its condition in various Elasmobranchs, Amphibia, Reptiles, and Birds, we find the result in favour of GEGENBAUR's view, and may summarise the whole, with most probability, as follows:—

The dorsal, or somatic, head mesoderm consists anteriorly of three segments, equivalent to trunk myotomes, from which arise the muscles of the eyeball. The two posterior ones of these are continuous ventrally through the first two visceral arches with the anterior portion of the lateral plate mesoderm.

Behind these three segments comes an unsegmented portion of somatic mesoderm (= fourth somite of VAN WIJHE). This represents an unknown, probably large, number of myotomes which have lost their individuality and become condensed, owing to the fact that they now give rise to no muscles in the adult. All the visceral arches behind the first two belong primarily to this region, though in development a certain number of them appear further back—that is, the lateral plate portion of these myotomes has not become condensed like their myotomic portions, owing to the presence of the functionally active gill pouches. This concludes the palingenetic part of the head. Primarily behind this, but now overlapping it owing to this condensation of the dorsal, myotomic portion, but not of the ventral, lateral plate part, we have the occipital myotomes forming the cœnogenetic head region, and continuous with the series of trunk myotomes. Like the hinder palingenetic head myotomes, some of the anterior ones belonging to the cœnogenetic part of the head have been lost, but at a much later period phylogenetically, as shown by the fact that some of these still appear and atrophy in the ontogeny of so many different forms of vertebrates.

It has just been maintained that it is the fourth somite of VAN WIJHE which represents the condensed somatic portion of the hinder palingenetic head somites. The variation in its extent and position in different forms is interesting. In Scyllium and Pristiurus it is under the auditory vesicle (VAN WJIHE) and also in Acanthias (HOFFMANN). In Ceratodus it is pro-otic (GREGORY), in Petromyzon it is metotic (though the first part of it is hypotic). In *Lepidosiren* and *Protopterus* its homologue is a long stretch of mesoderm, extending in front of, underneath, and behind the auditory vesicle. Some have concluded, from the result of direct observation, that this "somite" is an aggregate of two or more. BRAUS finds that in Spinax it probably represents two "somites" fused, the simpler condition in Scyllium and Pristiurus being probably due to a more complete fusion. Miss PLATT thinks that in Acanthias "three mesodermic segments lie above the hyoid arch" (quoted from BRAUS). SEWERTZOFF finds, behind the usual first three somites in the head of Torpedo, a fourth pro-otic and a fifth hypotic. In other cases, such as Petromyzon (KOLTZOFF), there is nothing to suggest that it may have a composite nature.

The above considerations show that direct observation of the embryological conditions of the myotomic portion of this "somite" are not against the view maintained above, namely—that its real nature is a mass of mesoderm, lying in the region of the auditory vesicle, and of various extent corresponding with the amount of reduction which the numerous segments more or less completely fused together to compose it have undergone. Besides the palingenetic segments which have gone to form it, it

probably also often contains the remains of anterior cœnogenetic head myotomes—for the number of occipital myotomes which appear in development often varies in nearly allied forms in which the occipital arch is certainly homologous. For example, the occipital myotome *w* occurs in Ceratodus embryos, SEMON—and apparently, *v*, also in SEWERTZOFF's specimens—but not, or very seldom, in *Lepidosiren* or *Protopterus*. It is well known also that variation in the number of occipital myotomes takes place in individuals of the same species. It is very probable that in Petromyzon, where this "somite" gives rise to muscles which form a continuation of the trunk muscles over the head, it is really mainly a cœnogenetic segment.

As regards the number of these somites whose myotomic parts have fused up and ultimately disappear, which, if the gill slits were originally segmentally placed, corresponds to the ancestral number of visceral arches, *minus* the first two, it is of interest to notice that the number of vagus roots in *Lepidosiren* larvæ is quite irregular. They seldom correspond even on the two sides of the same individual. For instance, in an embryo of stage 31+ the vagus fibres leave the medulla in twelve places on the left side and eleven on the right. In one of stage 38 there are ten outlets on the left side and seven on the right. It is significant, in connection with any attempt to estimate the number of these fused segments by the number of vagus roots, that in the older larva (1) the number of outlets is smaller than in the younger one, and (2) they are so arranged that the ten outlets on the left side might be regarded as collected into six "roots," and the seven on the right in five "roots," while it was impossible in the younger larva to allocate the outlets into "roots" in this way.

As will be seen immediately (p. 622), the region of the alimentary canal and its musculature innervated by the vagus shows during ontogeny a backward movement relative to the somatic trunk mesoderm (more correct morphologically, though less so descriptively, a forward movement of this trunk mesoderm over the vagus innervation region), similar to that which we suppose to have taken place phylogenetically in the case of the visceral arches. As regards the branchial region itself in *Lepidosiren* and *Protopterus*, no further backward movement of it relative to the trunk myotomes is observable after the branchial outgrowths have made their first appearance. In fact, in late larval life the posterior branchial arches actually move forwards, so that the whole branchial region comes to lie in front of the middle of the auditory capsule. The condensation of this region, thus brought about, obviously corresponds with its loss of functional importance. If, however, we take the vertebrate in which the branchial region occupies the greatest extent—*i.e.* Cyclostomes—we find the opposite. By the time the eight gill pouches in Petromyzon are formed, the posterior one is ventral to the seventh metotic myotome. This is the most anterior myotome to send a bud to the sub-branchial musculature (NEAL, KOLTZOFF). Later—in a larva of 8 mm. (KOLTZOFF)—the branchial region extends to beneath metotic myotome 13, breaking through the sub-branchial processes of myotomes 7–13 as it travels backwards.

Now it is quite possible to give an interpretation of this process exactly the oppo-

site to that of NEAL or KOLTZOFF. We may regard the later extension of the branchial region under the metotic myotomes 8–13 as a continuation of the process by which it extended backwards under the anterior metotic myotomes (or these grew forward over it). At first the branchial region was in the palingenetic part of the head. Then the somatic portion of this began to atrophy, its place being taken by the anterior trunk myotomes. This was doubtless helped by the disappearance of whole somites of the branchial region, including their visceral arches and pouches, compensated by increase in size of the individual gill clefts which were left,—a process which everyone agrees has taken place. As the anterior trunk myotomes progressed forwards over the branchial region, their sub-branchial processes got successively severed from their dorsal parts. Owing to the shortening of the ontogenetic recapitulation of the phylogeny, the branchial region reaches back as far as myotome 7 (metotic) before these have begun to form their ventral outgrowths. Consequently the anterior ones do not now form them at all, their place being taken by the outgrowths from the myotomes directly behind the branchial region. As, however, the process of backward extension into the trunk region is not finished by the time of the formation of the sub-branchial processes, the continuation of it recapitulates more fully the phylogeny, being accompanied by the successive severance of these processes from their myotomes.

Note on the conception of the vagus as a collector for the splanchnic fibres of the occipital nerves :—

The only *direct* evidence I know of supposed to be in favour of this view is the fact, made use of by KOLTZOFF, that in Petromyzon the dorsal anterior spinal nerves anastomose with the ramus branchio-intestinalis. It is difficult to see, however, how a *peripheral anastomosis* between these nerves can be a stage towards the condition presumed by this theory for all higher vertebrates—that is, that the splanchnic fibres of these spinal (now occipital) nerves leave the medulla through the ramus branchio-intestinalis, instead of through the trunks of the nerves to which they belong. Moreover, there seems to be no inducement for the splanchnic fibres of the occipital nerves to shift their point of exit from the central nervous system forward from the somatic fibres of the same nerves while the area of distribution of these splanchnic fibres is at least not in front of that of the somatic ones.

Ib. Lateral Plate Mesoderm in Head and Neck, and Constrictor pharyngis.

In stage 23+ we saw that the lateral plates of each side were still wide apart except at the extreme front end of the head, where they meet ventral to the "stomodæum." In the trunk the pronephrocœles have appeared, but ventral to this the

mesoderm is unsplit, while in the head the somatopleural and splanchnopleural mesoderm have separated in the anterior median portion of the lateral plate to form the rudiment of the pericardium. This cavity extends also for a short distance backwards into the still paired portion of the lateral plate on each side.

By stage 30 the lateral plates have not yet met below the yolk sac in the trunk. They have split in the region of the first few trunk myotomes. The cavity so formed (cœlome) is continued forwards in the dorsal part of the lateral plate in front of this region, right up into the pericardium (pericardio-peritoneal ducts—HOCHSTETTER). At present these narrow canals form the only communication between pericardium and general cœlome.*

At a slightly later stage (31+) the ventral parts of the lateral plates between pericardium and the rest of the cœlome have split, leaving an intermediate part which never splits. The cœlome and pericardium are therefore now connected—

1. By paired dorsal pericardio-peritoneal ducts. These connect the pericardium with the pronephrocœles, which are now nearly cut off from the rest of the cœlome.
2. By wide paired, ventro-lateral passages, running between the liver and body wall.

Both these connections become obliterated about stage 34 or 35.

At stage 30 the pericardio-peritoneal duct on each side lies, posteriorly, on the dorso-lateral border of the yolk sac; but further forward, where the œsophagus is being constricted off from the underlying yolk sac, it lies in the angle between the two. Further forward still, where the pharynx is completely folded off, the ducts lie on its ventral side. It lies altogether ventral to the branchial ridge.

The inner walls of these ducts, which are applied to the solid mass of endoderm representing the developing pharynx, are seen at this stage (30) to be budding off mesenchymatous cells between themselves and the pharynx (Plate fig. 1). Over the rest of the wall of the duct the nuclei are distributed very sparsely and have their long axes parallel to the direction of the wall, while on the inner wall the nuclei are thickly packed, have their long axes at right angles to the wall, and are several layers thick. The nuclei of the outer layers are less closely packed, as if moving away from their place of origin.

By stage circ. 31 these cells have accumulated enormously, and form a thick layer investing the pharynx ventrally and laterally.

In stage 31+ we find muscle fibres developing in this mass of cells, forming the ventral and lateral parts of the *constrictor pharyngis* of WIEDERSHEIM.

The ramus muscularis of the vagus can be definitely traced into this muscle from now onwards.

At present the pharynx or œsophagus is free from muscle dorsally, but at this stage (31+) a ventral outgrowth of cells from the occipital myotome y (possibly, but not probably, the outgrowth extends on to x and z also) is taking place. This is the

* I here use the term cœlome in its widest sense, without prejudice to the question as to whether the pronephrocœles belong to segmented or unsegmented mesoderm.

rudiment of a muscle which will unite with the muscle already formed as just described on the ventral and lateral sides of the pharynx to complete the constrictor pharyngis. It will form the "dorsal part" of this muscle of WIEDERSHEIM.

Plate fig. 2 shows this outgrowth from *y*, and also the extreme front end of the ventral portion of the constrictor. In this section, although it is slightly behind the position of the section shown in fig. 1, we have the posterior portion of the pericardium cut, owing to this having moved backwards since stage 30.

Thus the "dorsal part" of WIEDERSHEIM is somatic in origin, the ventral part splanchnic.

Fig. 3 shows the condition of the muscle rudiments at stage 34.

The two constituents have coalesced to form a complete sphincter muscle. The limits of the two components are marked by the connective tissue intersections.

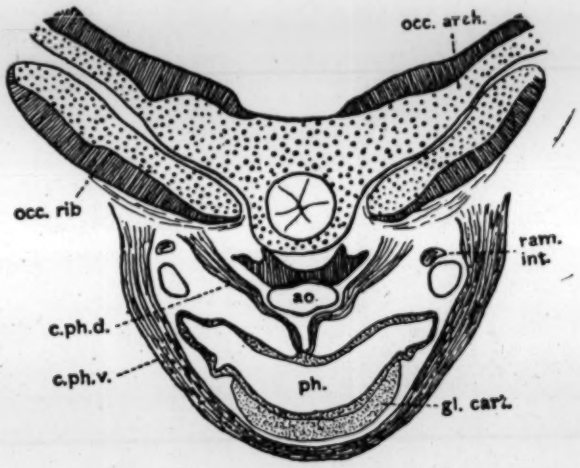

FIG. 5.—*Protopterus*, 5·5 cm. transverse section through the occipital region, showing the relations of the dorsal and ventral parts of the constrictor pharyngis. *ao.*, aorta; *c.ph.d.*, dorsal part of "constrictor"; *c.ph.v.*, ventral part of constrictor; *gl. cart.*, glottis cartilage; *occ.arch.*, occipital arch; *ph.*, pharynx; *ram.int.*, ramus intestinalis of vagus.

At this stage and onwards the occipital nerve *y* can be distinctly traced into this muscle.

At present this muscle seems to act as a simple constrictor, as named by WIEDERSHEIM (*cf.* Plate fig. 3). But later on, the ventral, splanchnic portion attaches itself to the auditory capsules, occipital ribs, and axial skeleton, and so is able to act as a constrictor by itself, by compressing the pharynx between itself and the notochord (text figure 5). As described by WIEDERSHEIM, a part of this becomes differentiated as the dilatator of the glottis—(posterior to the section in text figure 5). The dorsal, somatic portion of the muscle becomes attached to the occipital rib, and in the middle line to the dorsal wall of the pharynx, and so appears to act as a *dilatator pharyngis* by raising the dorsal wall of the otherwise dorso-ventrally compressed, slit-like cavity of this part of the alimentary canal (see the figure).

The probability suggests itself that the dilatator action of the dorsal part of the muscle is put into use during inspiration, and that the ontogenetic change from a simple (potential) constrictor to a compressor + dilatator is a true recapitulation of its phylogenetic history.

The foregoing description of the development of these muscles applies to *Lepidosiren*. The gaps between the stages of *Protopterus* were too great to allow the development to be followed with such detail. The later condition and innervation are the same in the two genera.

We have already seen good reason to believe that the anterior trunk myotomes come to be dorsal to visceral arches belonging genetically to a region in front of them. In the case of the constrictor pharyngis, which is also a structure belonging to the vagus region, differential growth actually brings about the same result during development. The facts are as follows:—

In stage 30 (*Lepidosiren*) the posterior limit of the region of the pericardio-peritoneal ducts from which the future muscle cells are being budded off is level with the hind end of the vagus ganglion, and under myotome *y*, a large part of the region being altogether in front of the occipital myotomes—*i.e.* in the palingenetic part of the head.

In stage 31 (*Lepidosiren*) the splanchnic portion of the constrictor reaches back to the myoseptum between *z* and 1 (the first post-occipital myotome).

In stage 38 (*Lepidosiren*) it goes back to at least myotome 5.

In a *Protopterus* larva of 5·5 cm. it goes back to at least myotome 6.

The ramus muscularis follows the extension of its muscle.

The backward extension of the ventral part of the constrictor carries the dorsal part back with it, though not so far, thus—

At its first appearance (stage 31+) it is entirely confined to the region ventral to the occipital myotome *y* (*Lepidosiren*).

By stage 38 it stretches back as far as myotome 2 (*Lepidosiren*).

In the 5·5 cm. *Protopterus* it stretches back to myotome 3.

The anterior ends of both parts of the constrictor remain approximately fixed.

Differential growth also results in a shifting backwards relative to trunk myotomes of the region of the alimentary canal supplied by the sensory branches of the vagus (ramus intestinalis), as shown by the position of the glottis (which is supplied by this nerve) at different stages.

In stage 31 (*Lepidosiren* and *Protopterus*) the anterior boundary of the glottis rudiment is opposite the posterior boundary of the vagus ganglion (under myotome *y*).

In stage 34 (*Lepidosiren*) it is opposite myoseptum *z*–1.

In stage 38 (*Lepidosiren*) it is opposite myotome 3.

In the 5·5 cm. *Protopterus* it is opposite myotome 3.

The outgrowth of the lungs from the glottis region of course carries the sensory distribution of the vagus much further back still.

The cases of the constrictor pharyngis and of the glottis therefore present before our eyes a partial recapitulation of the process which has resulted in the present position of the posterior visceral arches ventral to trunk myotomes which really belong to a region posterior to them. For the disappearance of the myotomic mesoderm properly belonging to the branchial region has resulted in a forward movement of the anterior trunk myotomes over the ventral portion of this region—which includes everything innervated by the vagus—to partially take its place.

II. The Occipital and Anterior Trunk Myotomes and Nerves.

There are three occipital myotomes of *Lepidosiren* and *Protopterus* (*x*, *y*, *z*). Of these, myotome *x* wholly disappears, *y* gives rise to the dorsal part of the constrictor pharyngis, and also contributes to the hypoglossal musculature (coraco-hyoid), *z* contributes to the coraco-hyoid, as does also myotome 1. Myotomes 2, 3, 4, and in *Protopterus* 5, contribute to the musculature of the pectoral fin.*

IIa. Cervical (Hypoglossal) and Brachial Plexuses and Occipital Nerves.

Text figure 6 shows clearly enough the condition of these plexuses in a *Lepidosiren* of stage 38. The cervical plexus is formed from the nerves *y*, *z*, and 1, the brachial plexus from 1 and 2. As will be shown presently, the nerve fibres joining the brachial plexus through N1 probably do not enter the fin.

In younger *Lepidosiren* larvæ there is an additional branch to the brachial plexus from N3. This is shown in the figure as a dotted line (3 *br*). This branch runs under the occipital rib, the trunk of N1 + N2 over it. The branch from N3 can be observed to be atrophying in successive stages, and ultimately apparently disappears.

In *Protopterus* the brachial plexus is much more extensive, reaching from N1 (or probably, as in *Lepidosiren*, more strictly speaking from N2—see p. 629) to N5 inclusive. The constituents from NN 3, 4, and 5 are joined into a collector which runs underneath the occipital rib like the branch from N3 in *Lepidosiren*.

* Henceforth the myotomes are spoken of as M*x*, M*y*, M*z*, M1, M2, etc., and the nerves as N*x*, N*y*, etc.

IIB. Embryonic Condition of the Occipital and Anterior Trunk Nerves and Myotomes.

In no larva of either genus have I found the nerve *x*.* The nerves *y* and *z* are always present; N*y* is very thin. Both have ventral roots only. Sometimes N1 has a dorsal ganglion, sometimes not. This is more often present in *Protopterus* than in *Lepidosiren*. In both genera there is a great deal of variation in regard to this point, irrespective of the stage of development. In *Lepidosiren* the ganglion

is present on both sides in 2 specimens—stages 29+ and 34.
,, one side only in 6 ,, — ,, 30, 30, 34, –35, circ. 35, 38.
is absent altogether in 12 ,, — ,, 31, circ. 31, 31+, 32, 32, 32+, 32+, –35, –35, 36, 36+, 38.

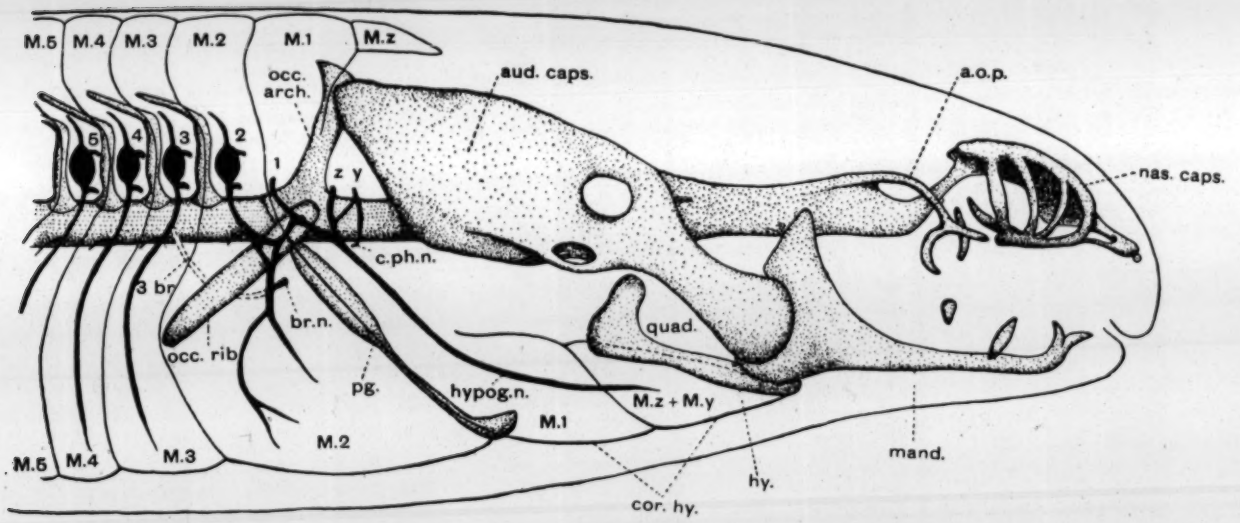

Fig. 6.—Cervical and brachial plexuses in *Lepidosiren*, from a reconstruction (by Graham Kerr's method), of a larva of stage 38. The chondrocranium at this stage is shown. *a.o.p.*, ant-orbital process; *aud.caps.*, auditory capsule; *br.n.*, brachial nerve; *cor.hy.*, coraco-hyoid muscle; *c.ph.n.*, nerve supplying constrictor pharyngis (dorsal part); *hy.*, hyoid; *hypog.n.*, hypoglossal nerve; *mand.*, mandible; *nas.caps.*, nasal capsule; *occ.arch.*, occipital arch; *occ.rib.*, occipital rib; *p.g.*, pectoral girdle; *quad.*, quadrate; *My*, *Mz*, *M*1, etc., the myotomes; *y*, *z*, 1, etc., the nerves; 3 *br.*, branch from spinal nerve 3 to brachial plexus, added from a younger specimen. It can no longer be traced at this stage.

In *Protopterus* I found the ganglion present on both sides in 3 larvæ, of stages 30, 32, and 5·5 cms. on one side only in 2 larvæ, both of stage circ. 36, absent in one of stage circ. 36.

It is thus seen that the presence or absence of the ganglion is by no means altogether determined by the age of the specimen, but that we are dealing with a highly variable vestigial structure.

The succeeding nerves always have both dorsal and ventral roots.

Throughout development the occipital myotomes remain in the same position relative to the central nervous system, and, after its formation, to the occipital arch.

* I have not, however, made an exhaustive search for this nerve, not considering that the labour involved in *proving* its absence in a long series of embryos would be repaid by the value of the knowledge gained. Pinkus and Fürbringer found N*x* in specimens of *Protopterus*.

I could find no certain evidence for the existence of the occipital myotome *w*, which SEMON found to be the anterior occipital myotome in *Ceratodus*. From SEWERTZOFF's account it appears that in his specimens M*v* was also present. It is, however, difficult to identify the individual myotomes at early stages, owing to the lack of a fixed point of comparison. The nearest approach to such a fixed point is found in the anterior pronephrostome. The nephrotome separates from the myotome between stages 20 and 24, but even after this the nephrostomes do not seem to change their positions relative to the myotomes. From stage 29 onwards it is easy to recognise the different myotomes by their relation to the developing coraco-hyoid, etc. (as described later), and by their innervation. In six embryos of *Lepidosiren* distributed over stages 29, 30, 31, and 31+, the anterior pronephrostome was found in every case to be beneath M1 (fourth metotic). It is therefore constant in position from stage 29 onwards. If we assume that it is under M1 in all younger embryos too, it follows that in one specimen of stage 26, in which this was the fifth metotic, M*w* was present, and in one of stage 25+, in which it was the third metotic, M*y* was the anterior occipital myotome. I give the observations for what they are worth.*

Comparing the foregoing account of the occipital myotomes with Miss PLATT's account of Necturus, we see that they agree in that the single occipital arch is developed in the myoseptum between the third and fourth metotic myotomes. It has already been shown that as regards the development of the occipital region of the skull these Dipnoi resemble the Amphibia very closely, especially as regards its protometameric nature (the skull may become auximetameric in adult *Protopterus* by synchondrosis of the anterior neural arches with the occipital arch—FÜRBRINGER). The relations of the occipital and post-occipital nerves and myotomes to the occipital arch give no reason to suppose that the simple condition of this part of the skull in *Lepidosiren* and *Protopterus* is not truly primitive—that is, we suppose that the phylogeny of the Dipnoi, as of the Amphibia, did not include a stage with a complex occipital arch as at present found in Elasmobranchs, etc.

IIc. Derivatives of the Anterior Trunk Myotomes.

At about stage 29 the myotomes begin to put out their ventral processes (with the exception of M*x*, which does not form one). The series of ventral processes is interrupted by the presence of the pronephros, the nephrostomes of which, with the tubules

* In *Ceratodus* embryos SEMON found that the occipital myotomes reach up to directly behind the auditory vesicle. In one specimen, however, in which M*w* was absent, there was a corresponding gap between the auditory vesicle and the anterior occipital myotome *x*. In *Lepidosiren* and *Protopterus* there is a gap, about equal to the length of a myotome, between M*x* and the auditory vesicle, which might be thought to represent the position of M*w*. In the individual of stage 26, in which the anterior pronephrostome is under the fifth metotic myotome, this gap is as large as usual.

into which they open, are so much distended at this stage as to fill up almost the whole space between the cœlomic lining and ectoderm, which space, in front of and behind this region, is occupied by the ventral processes of the myotomes—see text figure 7. The bulk of the pronephros is situated under M1 and M2, the anterior and posterior

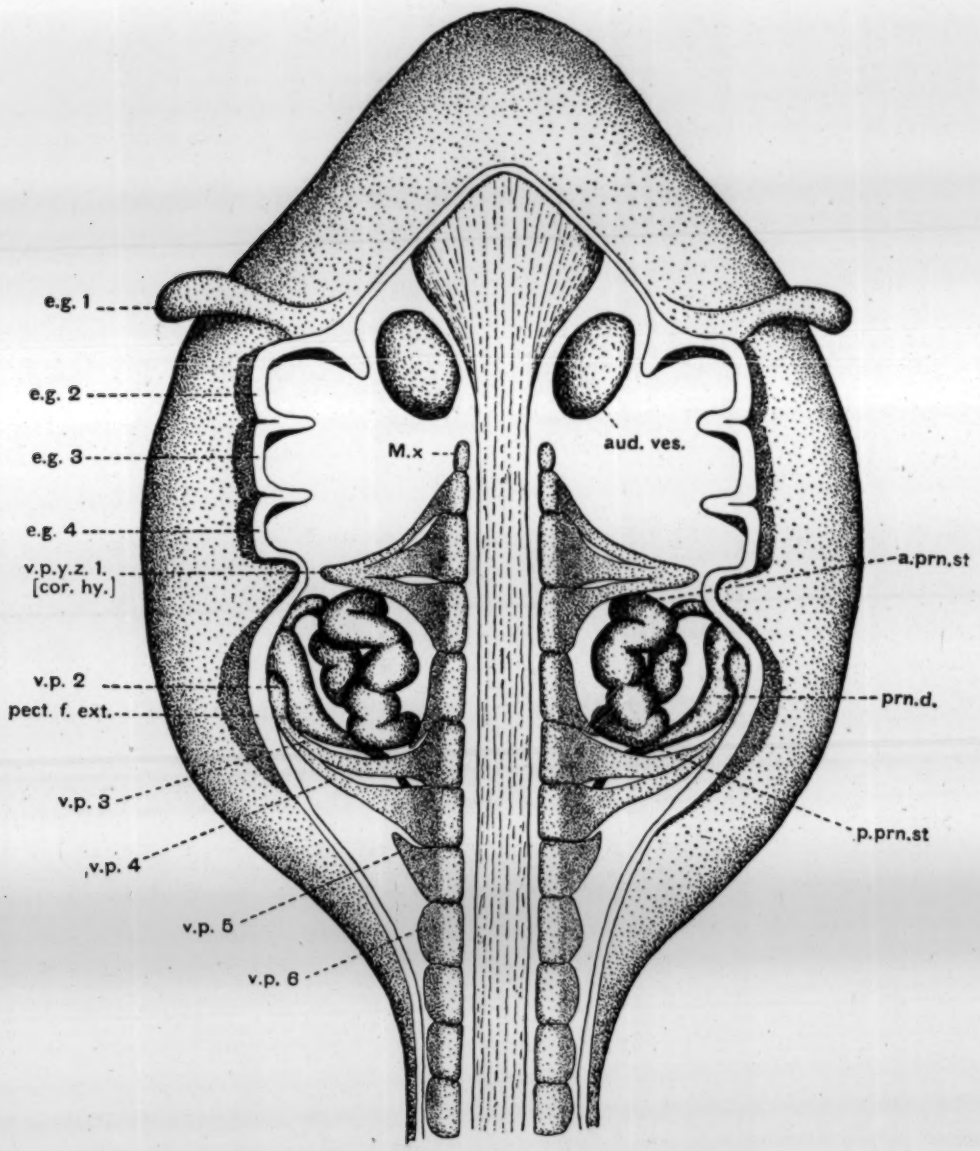

FIG. 7.—*Protopterus*, stage circ. 29. Reconstruction of a thick horizontal slice by GRAHAM KERR's method. Only the ectoderm, central nervous system, auditory vesicles, myotomes and pronephros are shown. *a.prn.st.*, anterior pronephrostome ; *aud.ves.*, auditory vesicle ; *cor.hy.*, coraco-hyoid muscle ; *e.g.*, 1, 2, etc., first, second, etc., external gill ; *pect.f.ext.*, external projection of pectoral fin ; *p.prn.st.*, posterior pronephrostome ; *prn.d.*, pronephric duct ; *v.p. y*, *z*, 1, etc., the ventral processes of the corresponding myotomes. The ventral end of *v.p.* 2 has broken off from the rest of M2 and is fused to the ends of *v.pp.* 3 and 4.

pronephrostomes being underneath these myotomes respectively. The pronephros thus offers an obstruction to the outgrowth of the ventral process of M1 and M2, which is avoided by the forward slope of the M1 process and the backward slope of the M2 process (fig. 7). The three myotomes in front of the pronephros (1, *z*, *y*,) give rise to

the hypoglossal musculature (coraco-hyoid), and the three (*Lepidosiren*) or four (*Protopterus*) behind provide mesoderm for the pectoral fin.

Development of the Coraco-hyoid Muscle.

The disposition of the ventral processes which go to form the coraco-hyoid in *Protopterus* is seen in text figure 7. The figure would do as well for *Lepidosiren* as regards this point.

At stage 30 these three ventral processes have separated from their myotomes and travelled downwards and forwards. They are so completely fused together that no trace of a division between the contributions of the different myotomes could be found. As development proceeds, the compact mass of mesoderm so formed on each side gradually grows forwards along each side of the pericardium, finally to meet each other in front of and ventral to it, and become inserted in front into the rudiment of the hyoid arch and behind into the pectoral girdle. Thus the strong coraco-hyoid muscle is formed. On its differentiation into muscular tissue, the rudiment becomes divided up, by a connective tissue intersection, into two segments (M1 and MM$z+y$) (text figure 6). Fürbringer finds that in the (adult) specimens of *Protopterus* examined by him the anterior of these two segments was partially subdivided into two, which we now see to be Mz and My. I could not find this subdivision in any of my larval *Protopterus*, nor in larval or adult *Lepidosirens*. However, in *Protopterus* My contributes much less substance to the muscle rudiment than Mz or M1, and in *Lepidosiren* still less. This is also shown by the very small bundle of nerve fibres contributed by Ny to the cervical plexus.

Development of the Pectoral Fin.

The mesoderm of the pectoral fin is supplied by the ventral processes of MM 2, 3, and 4 in *Lepidosiren*, and 2, 3, 4, and 5 in *Protopterus*. The general disposition of these ventral processes, and their relations to the pronephros, etc. in *Protopterus*, is shown in figure 7. This text figure would apply equally well to *Lepidosiren* if the ventral process of M4 were made like that of M5, and that of M5 like M6, etc.

We will take our detailed account from *Lepidosiren*. As already mentioned, the mass of the pronephros causes the ventral process of M2 to be displaced backwards, and it runs out through a narrow space opposite myoseptum M2–M3, left between the posterior pronephrostome, ventral process M3, and ectoderm. Presumably in consequence of its restricted space, it very early loses its epithelioid character, and breaking up into mesenchyme, looses itself from its myotome, and slips ventro-laterally

between pronephros, ventral process M3, and ectoderm. The loose mesenchymatous mass then spreads out below the pronephros, occupying its proper position ventral to M2, but separated from it by the pronephros. It is in this condition in stage 30 (Plate fig. 4; shown also in *Protopterus* in text figure 7—*v.p.* 2).

The ventral process of M3, which does not separate from its myotome like that of M2, is shown in Plate fig. 5, and under a higher magnification in fig. 6. An increase in nuclei has taken place in the outer wall of the process. Between it and the ectoderm there is a slight concentration of mesenchyme, clearly derived from the same source as the general mesenchyme.

Simultaneously with these changes in the mesoderm, or possibly before them, though of this I could not quite satisfy myself, the ectoderm shows an increase of nuclei in this region (fig. 6).

At a slightly later stage the position of the limb is marked by an external projection, due to an increased accumulation of mesenchyme cells beneath the ectoderm. This is now considerably thickened here. It is irregularly two-layered. The middle of the projection is opposite the myoseptum M1–M2.

The ventral processes of M2 and M3, which take the chief part in muscularising the pectoral fin, have at this stage shifted their positions relatively to their myotomes. That of M2 has moved forwards so that it now lies wholly under M1. It is in the form of an elongated, moderately compact mesenchymatous mass. That of M3, though remaining attached to its myotome, is much pulled forward, so that the end of it comes in contact, and practically fuses, with the ventral process of M2 (*cf.* text figure 7), at the level of myoseptum M1–M2; *i.e.* the ventral processes of both M2 and M3 reach a full myotome in front of the one to which they belong. The outer wall of the ventral process M3 has broken up, but the inner wall is always recognisable as a more or less definite epithelium.

By far the greater number, if not all, of the mesoderm cells of the fin (apart from the mesenchyme) are derived from M2 and M3.* At our present stage, though, the ventral process of M4 is directed strongly forward, so as to reach up nearly to the front end of M3, underlying the posterior part of the obliquely forward sloping ventral process M3. The tip ends raggedly, as if cells were being given off to the fin rudiment, but whether this is or is not the case could not be determined directly by observation. However, the forward slope of this ventral process towards the fin rudiment (the ventral processes of M5 and of the myotomes behind this slope backward) makes it probable that it did contribute to the mesoderm of the fin at one time, though, if it still does, the absence of a branch from N4 to the brachial plexus shows that its contribution atrophies during ontogeny.

We saw that at its first appearance the centre of the external projection forming the rudiment of the fore-limb was opposite myoseptum M1–M2,—*i.e.* in front of the

* The contribution of cells from M3 seems to be considerable, yet the nerve from sp. nerve 3 to the brachial plexus disappears during development—p. 623.

myotomes participating in its muscularisation. It retains this position relative to the myotomes throughout life.

The foregoing account applies to *Lepidosiren*. In *Protopterus* the scarcer material did not allow the development to be followed in such detail. It shows, however, that the ventral processes of MM 2, 3, 4, and 5 slope forward towards the fin rudiment, the myotomes behind 5 having ventral processes running straight downwards or sloping backwards (text figure 7). The pronephros has the same relations to the fin rudiment as in *Lepidosiren*. The attachment of the limb is approximately in the same position (at the front end of M2).

The indication of M5 taking part in the muscularisation of the fin is in agreement with the composition of the brachial plexus in this genus (p. 623).

After giving off the myoblasts to the fin rudiment, the ventral processes concerned again become compact, definitely outlined masses (but more than two-layered), and take their part in the formation of the obliquus and rectus muscles, similarly to the ventral processes in the hinder part of the body. It is worthy of note that whereas in an earlier stage the ventral processes of M1 and M2 are very widely separated, the gap between them is obliterated by forward growth of M2 and M3 (*cf.* text figure 6), so that in the adult the coraco-hyoid (MM *y*, *z*, 1) forms a direct continuation of the rectus muscle (MM 2, 3, 4, etc.). The pectoral girdle is situated in the myoseptum M1–M2.

As was stated on p. 623 the nerve 1 contributes both to the cervical and the brachial plexus. It is probable, however, that the nerve fibres from N1 do not enter the limb. As we have seen, the ventral process of M1 seems to be absolutely cut off from participation in the fin mesoderm by the presence of the pronephros, and it seems probable that the fibres from N1 leave the brachial plexus by some other of the numerous branches given off by it to the composite muscle inserted into the occipital rib (the costal element of the neural arch in the myoseptum M*z*–M1). It is, of course, just possible, though unlikely, that there might be some interchange of substance between the proximal portions of the ventral processes of M1 and M2, which are in contact (text figure 7).

FÜRBRINGER emphasises the fact that from Dipnoi onwards the cervical and brachial plexuses tend to become distinct, and we see that it probably is so in *Lepidosiren* and *Protopterus*.* (The separation is sometimes complete in Amphibia, and probably always in the Amniota.) In all other fishes the plexuses overlap, some nerve or nerves sending fibres to both hypobranchial and pectoral girdle muscle. The overlapping is greatest in Elasmobranchs.† May we not seek the cause of this separation in a condition of the pronephros, together with a flattening out of the ventral processes over a

* Note, however, that I make the separation between N1 and N2 instead of between N*z* and N1, as FÜRBRINGER makes it in *Ceratodus* and *Protopterus*.

† It must, however, be noted that FÜRBRINGER considers an extensive overlapping to be secondary, as this condition is found more highly developed in the less primitive Elasmobranchs.

large yolk sac, such as is found in the Dipnoi? In *Lepidosiren* and *Protopterus* it seems a mechanical impossibility for M1 to participate in the muscularisation of the pectoral fin, or for M2 to do so in the coraco-hyoid. Here at any rate we have a condition which almost precludes the muscularisation of these two regions from any common myotome—a condition which would lead to the stage of things found in the terrestrial vertebrates.

A slight variation in the position of the anterior pronephrostome will of course have to be accompanied by a corresponding shifting of the division between the two plexuses.

So far as *Lepidosiren* and *Protopterus* are concerned, there is strong evidence that the pectoral fin has recently undergone a forward migration, and Braus (1898) comes to the same conclusion for *Ceratodus*. We find, in the two former genera, that the fin is situated in front of the myotomes participating in its muscularisation, and the evidence is conclusive that posterior myotomes are successively ceasing to take part in it. In *Protopterus* the first of the brachial plexus nerves, N2 (not counting the contribution from N1), is the largest, and the size of the branches from the other nerves diminishes as one passes backwards. Also M2 and M3 contribute the bulk of the mesoderm. In *Lepidosiren* the reduction has gone further, for the branches from N5 and N4 have gone completely, and that from N3 vanishes during development. We are thus left with the remarkable result that the pectoral fin in *Lepidosiren* is probably innervated by one spinal nerve only (N2).

A summary of the derivations of the anterior myotomes in the Dipnoi is given in the following table. *Necturus* is added for comparison.

	Position of Anterior Pronephrostome.	Coraco-hyoid.		Pectoral Fin.	
		Myotomes muscularising.	Nerves innervating.	Myotomes muscularising.	Nerves innervating.
Ceratodus	M1. (S)	*y*, *z*. (S)		1, 2, 3. (S)	*a*, *b*, *c* (3). (S)
					z, *a*, *b*, 3, 4–11. (B)
			x, *y*, *z*. (F)		*a*, *b*, 3, 4, 5. (F)
			y, *z*. (F)		*a*, *b*, 3, 4, 5, 6. (F)
Protopterus	M1. (A)	*y*, *z*, 1. (A)	*y*, *z*, 1. (A)	2, 3, 4, 5. (A)	?1, 2, 3, 4, 5. (A)
			x, *y*, *z*. (F)		*a*, *b*, 3. (F)
			y, *z*. (F)		*a*, *b*, 3, 4. (F)
Lepidosiren	M1. (A)	*y*, *z*, 1. (A)	*y*, *z*, 1. (A)	2, 3, ?4. (A)	?1, 2, (and 3 in embryo). (A)
Necturus	M2. (P)	*z*, 1, 2. (P)	1, 2, 3. (F)		
			2, 3. (F)		

Authorities:—A, the Author; B, Braus; F, Fürbringer; P, Miss Platt; S, Semon.

III. Development of the Pelvic Fin.

The following account applies to *Lepidosiren.*

The pelvic fin makes its appearance at a slightly later stage than the pectoral. The latter is first indicated in stage 30, the former in stage 31. Here there is a great proliferation of cells from the somatopleural mesoderm taking place in the region of the future fin rudiment. The ectoderm has also begun to be thickened in the same place, viz. opposite M56. The limits of the ectodermal thickening are hard to determine exactly, but it certainly does not extend appreciably beyond M56 on either side. As regards the myotomes, all of these behind the first few are giving off mesenchyme cells from the ventral processes (ventral connective tissue of Maurer), and this fact makes it impossible at this early stage to determine whether they have begun to give off mesoderm cells to the fin or not. At any rate, if they have, this process has not proceeded so far as the modification in the somatopleural mesoderm and ectoderm.

In stage 31 + the fin rudiment is well established; there is now a distinct projection from the surface (Plate fig. 7). All these sources of the fin material—somatopleural, myotomic, and ectodermal—are in great activity. The ectodermal thickening, due to a proliferation of nuclei, is considerable. It extends in the embryo examined from the middle of M49 to the hind end of M52 (this corresponds to MM53-56 of the embryo mentioned in the previous stage, the cloaca in the latter being opposite M58 instead of M54 as in the former. This point will be returned to later). This is the greatest extent of ectodermal rudiment, there thus being a very long interpterygial zone without any ectodermal modification.

It is impossible to put an exact limit to the number of myotomes taking part in the fin rudiment. As in the previous stage, all the myotomes behind the first few are giving off connective tissue cells from their ventral processes, but the process is enormously exaggerated in the case of the myotomes just dorsal to the ectodermal thickening, diminishing rapidly from the myotomes behind and gradually from the ones in front. From the examination of sagittal sections of this stage, however, there appear to be 8 myotomes taking part in providing the fin rudiment with mesoderm cells. This corresponds with the maximum number of nerves found taking part in the pelvic plexus. This plexus in a larva of stage 34 was composed of NN45–53, and in stage 38 of 47-53. In both cases there was also a doubtful branch from N54.

So far as it goes, the *Protopterus* material shows the same features as *Lepidosiren.*

The accompanying table gives the position of the cloaca and of the pelvic fin in larvæ of various stages. The position of the limb is defined by the attachment of its post-axial border, as, owing to the backward slope of the limb, this point is sharply marked. In the first three the position of the posterior limit of the ectoderm rudiment is given.

Stage.	*Lepidosiren.*		*Protopterus.*	
	Pelvic Fin, Post-axial. Myotome.	Cloacal Aperture. Myotome.	Pelvic Fin, Post-axial. Myotome.	Cloacal Aperture. Myotome.
31	56	58		
31+	52–53	54		
31+	52–53	54		
32	55	57	37	40
34	54	56	36	38
34	52 (pelvic plexus NN45–53+?54)	54–55		
circ. 35	53	56		
36	54	57–58	36	39
38	56 (pelvic plexus NN47–53+?54)	58		
6·3 cm.	...	...	35–36	37
6·9 cm.	...	...	34–35	36–37
7·3 cm.	...	...	35	37
7·4 cm.	...	...	34	36
7·5 cm.	...	...	35	37
7·8 cm.	...	...	34–35	36–37

The total number of post-occipital myotomes in *Lepidosiren* is about 110, in *Protopterus* about 65. In *Ceratodus* the pelvic fin is under spinal ganglia 28–30 (SEMON).

Examining this table we find that the variation in the position of the pelvic fin is quite noticeable, but in *Lepidosiren* it is neither further forward nor backward on the average in older than in younger individuals. In *Protopterus* the table gives a slightly further forward position of the fin in older than in younger individuals. In this genus, however, the number of young specimens examined is not sufficient to draw safe conclusions from. Any variation in the position of the fin is closely associated with a corresponding variation in the position of cloacal aperture in both genera. The pelvic girdle maintains a nearly constant distance in front of this opening. Thus the position of the pelvic fin appears to be determined by the position of the earlier appearing cloaca, and the variations now observable in its position are not of the same nature as those variations which resulted in the backward migration of the fin relative to the cloaca which has to be assumed on the GEGENBAUR theory. The variations in the position of the cloaca are not due to a "migration" of this structure relatively to the myotomes either, but to an increase or decrease in the total number of myotomes in the body. This is made apparent by the comparison of the two genera, which shows that in *Lepidosiren* the position of the cloacal aperture is about M56, the total number of post-occipital myotomes being about 110, and in *Protopterus* it is opposite M38 (about), corresponding with the shorter length of about 65 myotomes.

On the other hand, there is considerable evidence that the fin has undergone a real migration in a backward direction in the past. For one thing, we find it at the hind end of its innervation region. Then the history of the ectodermal rudiment points in the same direction. It has just been made obvious that the position of the fin in

different stages cannot be compared without taking into account the individual variation in the position of the cloaca. In comparing different stages, it is most convenient to transmute all the values into the corresponding values for a hypothetical specimen of that stage in which the cloaca is in some standard position, say under M56, and the pelvic fin two myotomes in front of this (which are the approximate averages for *Lepidosiren*). Proceeding thus, we see that in the youngest embryo described the ectodermal thickening may be taken as opposite M54, since in the actual specimen it was at M56, the cloaca being at M58. At stage 31+ (second stage described) it may be taken as opposite M51 (middle) to M54 (hind end). In stage 38 the width of the attachment of the limb is much less—about the length of one myotome, and this one M54. I interpret this as follows:—The long stretch of modified ectoderm in stage 31+, of which only the *hinder end* represents the rudiment of the future limb, marks the backward track, or at least the hinder part of it, of the fin. This hinder part is the first to appear, in accordance with the well-known embryological rule that the rudiments of more complex structures tend to appear earlier than less important organs of equal, or even greater, phylogenetic age. (*Cf.* the very precocious development of the eye.)

In fact, we may say that the evidence supplied by *Lepidosiren* points to the conclusion that the pelvic fin has migrated from a more forward position as far backward as the obstruction of the cloaca allowed.

I should like to draw attention here to certain phenomena of developmental mechanics which might have resulted in a tendency to backward migration into the trunk of the posterior visceral arches.

Firstly, the topographical relations of the ectodermal rudiments to the ventral processes of the myotomes which take part in muscularising the fins, *i.e.* the convergence of a long stretch of the latter towards a comparatively small area of the former, points to the possibility that this ectodermal rudiment acts as the incentive for the myotomes in its neighbourhood to send out mesoderm cells to it. Analogous cases of the dependence of the development of one part of a structure upon the presence of another, earlier formed, part of it are known; for example, the development of a lens at the spot where the optic vesicle touches the skin in larvæ of *Rana palustris* and *R. sylvaticæ*, even when the vesicle has been cut out from its original position and displaced so as to be underneath quite another area of the skin; and, conversely, the failure of the lens to develop in the absence of the stimulus of contact between optic vesicle and skin (Lewis).

Secondly, we have the experiment of Harrison, of grafting the tail of *Rana palustris* on the body of *R. virescens* tadpole, in place of its own amputated tail, and *vice versa*. In these cases, for a long time the tissues of the two components are sharply marked off from one another by their specific coloration. He finds that the ectoderm

of the anterior member of the compound larvæ quickly extends backwards over the grafted-on tail, owing to the method of growth of the ectoderm by general proliferation, and of the myotomes by apical growth. This relative shifting is extremely great. Thus (p. 441) ". . . a given (ectoderm) cell located originally at the posterior limit of the fourteenth myotome moves during seven days to a point at least 2·5 mm. further peripherally (posteriorly), that is, through a distance equal to about fourteen segments."

This movement of a given ectodermal cell backwards over the underlying myotomes was found by HARRISON to be much greater the further back the cell was situated, owing to the fact that at the time of the experiment the tail region was growing very much more rapidly than the anterior region. He found by experiment, however, that there was a slight movement of the ectoderm in the same direction in the region of the pronephros and fore-limb. Still at a much earlier stage, when the trunk itself and the anterior portion of the tail are lengthening out more rapidly, it is extremely probable that a backward movement of any given point of the ectoderm over the underlying myotomes takes place to a nearly equal extent.

If the initial change in the ectoderm really acts as the stimulus to the development of the mesodermal portion of the fin rudiment, the bearing of HARRISON's experiment on the question of limb migration is obvious. Owing to the different method of growth of the ectoderm and mesoderm, and to the development of the anterior part of the body before the posterior part, any given point in the ectoderm, at first at the level of about, say, the first metotic myotome, will later on be far down the trunk. Hence the ectodermal rudiment of a structure originally at the hinder head region will tend to appear further back. If now the completion of the structure follows, by the self-regulative processes with which we are so familiar now, on the stimulus of this initial ectoderm rudiment—even when this is displaced from its original position (like the optic vesicle in LEWIS's experiment)—we have, as a pure result of this different method of growth of ectoderm and mesoderm, an effective cause of the backward migration of such posterior head structures into the trunk.

Of course this is not meant to supply a complete explanation of the present position of the limbs. It only shows how the mode of development of the vertebrate body may lead to a strong tendency to produce that backward movement of posterior head structures (postulated by GEGENBAUR's theory of the origin of the paired limbs) which has afforded material for natural selection to work upon in fixing the position of the limbs. The recent slight forward migration of the pectoral fin in Elasmobranchs (BRAUS) and Dipnoi must in any case be regarded as an entirely secondary acquirement.

I put this forward as a mere suggestion. I am well aware that without some firmer grounds to go upon than we have at present it is not worthy of consideration as a practical hypothesis. Nevertheless, I thought that if this were borne in mind, no harm would be done by recording the idea. Meanwhile we may consider one or two points which have bearings upon the question.

Different forms give different answers to the question as to whether the ectoderm

or mesoderm gives the first visible evidence of the presence of the fin rudiment. In *Ceratodus* (SEMON) the initial visible changes take place in both simultaneously, in both fins. In *Lepidosiren* I have described the changes as taking place approximately simultaneously in somatopleural mesoderm, myotomes, and ectoderm. If, however, either of the three starts first (in the pelvic fin), that one is probably the somatopleural mesoderm. BRAUS (p. 504), after reviewing the literature, comes to the conclusion that such variations exist in this respect in Elasmobranchs that no phylogenetic importance can be attached to it. As a rule, the first visible changes take place in the mesodermal structures, though the ectoderm has been described as being the first to exhibit the change in some forms (BALFOUR). Thus, so far as the actual visible course of development of the fins is concerned (especially the pelvic), the balance of evidence seems to be against the ectodermal portion of the rudiment acting as a stimulus to the mesodermal. The conditions in *Lepidosiren*, however, suggest that the ectoderm begins to exert its influence before visible changes take place in it. Here all the myotomes muscularising the pelvic fin are dorsal to or in front of the fin rudiment (ectodermal part), the ventral processes of the more anterior ones sloping strongly backward. I should interpret this, on the view here set forward, as due to the fact that the area of ectoderm which at stage 31 shows a proliferation of nuclei, the first visible ectodermal part of the fin rudiment, has been travelling backwards from a more anterior position, and by the time it has reached M45 (the most anterior myotome taking part in the fin muscularisation), has begun to take on the character of fin rudiment, though this has not yet resulted in a visible structural change. Still travelling back, it pulls the ventral processes of the myotomes after it, and by stage 31, when structural changes first appear, it is under M54.

The fact that the pelvic fin appears later than the pectoral is in accordance with this view, though it cannot be said to offer positive evidence in favour of it, the difference in time of the appearance of the two limbs being sufficiently accounted for by the general lagging behind of the development of the posterior region of the body.

IV. SUMMARY.

The head mesoderm in *Lepidosiren* and *Protopterus* never shows a segmentation corresponding to the trunk segmentation.

The eye muscles are derived from a continuous, extended source, probably corresponding to the first three somites of VAN WIJHE.

The mesoderm included in the first four visceral arches is, at the time of their formation by the meeting of the gill outgrowths with the ectoderm, attached to unsegmented somatic head mesoderm. That included in the fifth, sixth, and seventh

arches is ventral, but not attached, to the occipital myotomes, and does not therefore necessarily belong to them. The development of the pericardium in *Lepidosiren* and *Protopterus*, etc. shows by analogy that even when the mesoderm cut off by the posterior visceral arches is attached to the occipital myotomes, it is not necessary to believe that they belong genetically to the same somites. Probably the branchial region was formerly entirely in front of the occipital region which now overlaps it. The fourth pro-otic segment of VAN WIJHE probably represents a large number of fused myotomes to which all except the first two visceral arches belonged.

The cœlome and pericardium are connected at one stage by paired dorsal pericardio-peritoneal ducts, and by paired ventro-lateral passages between the liver and body wall. The inner walls of the pericardio-peritoneal ducts give rise to the ventral and lateral parts of the constrictor pharyngis. The dorsal part of this muscle is of somatic origin, being derived from myotome *y*. The muscle appears to undergo a change of function during ontogeny, from a simple constrictor to a separate compressor and dilatator.

The region of the mesodermal investment of the alimentary canal innervated by the vagus, both by its muscular and sensory fibres, actually extends to successively more and more posteriorly situated myotomes during development, owing to differential growths of the two structures. This gives us a partial recapitulation of the process which has resulted in the present position of the posterior visceral arches under trunk myotomes which belong genetically to a region behind them. The incentive to this differential growth of trunk myotomes over palingenetic head structures was the disappearance of the myotomic mesoderm of all that region innervated by the vagus.

There are three occipital myotomes, *x*, *y*, *z*. Of these, *x* vanishes entirely, *y* forms the dorsal part of the constrictor pharyngis, and contributes to the hypoglossal musculature. Myotome *z* contributes to this musculature, as does also M1. MM 2, 3, 4 in *Lepidosiren*, MM 2, 3, 4, 5 in *Protopterus*, muscularise the pectoral fin.

The occipital myotomes do not migrate relatively to the central nervous system.

The cervical (hypoglossal) plexus consists of NN *y*, *z*, 1, and the brachial of NN ?1, 2 (adult *Lepidosiren*), ?1, 2, 3 (young *Lepidosiren* larvæ), ?1, 2, 3, 4, 5 (*Protopterus*).

The nerve *x* has not been found in any specimen.

N*y* and N*z* have ventral roots only.

N1 has generally a dorsal ganglion in *Protopterus*, generally not in *Lepidosiren*. In the latter genus especially this vestigial structure is subject to a high degree of variation.

The anterior pronephrostome seems to be quite constantly in *Lepidosiren*, and nearly constantly in *Protopterus*, under M1.

The relations of the occipital myomeres, neuromeres, and scleromeres show that the single occipital arch in all young *Lepidosirens* and most * young *Protopterus* indicates a truly protometameric skull, and not one that has undergone reduction from an auximetameric condition.

* See *Trans. Roy. Soc. Edin.*, vol. xlv.

The separation of the hypoglossal and pectoral limb musculature, and hence of their nerve plexuses, is brought about by the relation of the pronephros to the ventral processes of the myotomes concerned.

The pectoral fin affords clear evidence that it has lately undergone a forward migration, and that posterior myotomes are successively ceasing to take part in it. True muscle buds are not formed, the cells being given off from the walls of the ventral processes.

The pelvic fin appears later than the pectoral. There is no sign of a continuous pectoral and pelvic fin rudiment. Apparently eight myotomes take part in its muscularisation, which agrees with the composition of the pelvic plexus. The pelvic limb gives evidence of a former backward migration of the same nature as that for the forward migration of the pectoral fin, together with additional evidence from the condition of the ectodermal rudiment. It has migrated backwards till stopped by the cloaca, the variations in the position of which it closely follows. A comparison of the two genera leads to the conclusion that these variations in the position of the cloaca are due to variations in the total number of segments in the body.

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EXPLANATION OF THE PLATE FIGURES.

[All the sections are drawn with the camera lucida.]

Fig. 1. *Lepidosiren*, stage 30. Transverse section through the pharyngeal region, between the third and fourth gill outgrowths. To show the origin from the inner wall of the pericardio-peritoneal duct of the myoblasts for the ventral part of the constrictor pharyngis. Zeiss A obj. 2 oc.

Fig. 2. *Lepidosiren*, stage 31+. Transverse section to show the origin of myoblasts for the dorsal part of the constrictor pharyngis from the myotome *y*. Zeiss A obj. 2 oc.

Fig. 3. *Lepidosiren*, stage 34. Transverse section through the same region as in fig. 2, to show the relations of the dorsal and ventral parts of the constrictor pharyngis at this stage. Zeiss A obj. 2 oc.

Fig. 4. *Lepidosiren*, stage 30. Transverse section through M2, to show the character of its ventral process. Zeiss A obj. 4 oc.

Fig. 5. Same specimen as fig. 4. Transverse section through M3. Zeiss A obj. 2 oc.

Fig. 6. A small portion of fig. 6, as marked, under a higher power (Zeiss D obj. 4 oc.). To show the ectodermal, mesenchymatous, and myotomic constituents of the pectoral fin rudiment.

Fig. 7. *Lepidosiren*, stage 31+. Transverse section through M51, showing the ectodermal, myotomic, and somatopleural constituents of the pelvic fin rudiment. Zeiss A obj. 4 oc.

EXPLANATION OF THE ABBREVIATIONS

ao., dorsal aorta.
art. arch., arterial arch.
br. r., branchial ridge.
ch., notochord.
cor. hy., coraco-hyoid muscle.
c. ph. d., dorsal part of constrictor pharyngis.
c. ph. d. r., rudiment of dorsal part of constrictor pharyngis.
c. ph. v., ventral part of constrictor pharyngis.
c. ph. v. r., rudiment of ventral part of constrictor pharyngis.
gang. vag., ganglion of the vagus.
int., intestine.
i. w., inner wall of myotome.
Mx, *My*, etc., the corresponding myotomes.
n., nucleus.
Ny, *N*2, *N*3, the corresponding spinal nerves.
o. w., outer wall of myotome.
pcdm., pericardium.
pect. f. ect., modification of ectoderm over pectoral fin rudiment.
pect. f. mes., mesenchyme concentration in pectoral fin rudiment.
pel. f. ect., modification of ectoderm over pelvic fin rudiment.
ph., pharynx.
p. p. d., pericardio-peritoneal duct.
p. prn. st., posterior pronephrostome.
prn. cœ., pronephrocœle.
prn. d., pronephric duct.
som., Somatopleural proliferation opposite pelvic fin rudiment.
v. p. y, *z*, 1, 2, 3, etc., the ventral processes of the corresponding myotomes.
y. g., yolk granule.

ERRATUM.

I should like to take this opportunity to correct a mistake in my paper on "The Development of the Skull and Visceral Arches in *Lepidosiren* and *Protopterus*" in Part I. of this volume. It is there stated (p. 51) that one of the nerves crossing the trabeculæ in the first rudiment of the *Protopterus* skull is a composite one, consisting of $V^3 + VII$ lateralis. This is an error, the two nerves being quite distinct. It is also stated (p. 56) that when the original foramen pro-oticum becomes divided, the division takes place between the nerves V^2 and $V^3 + VII$ lateralis. As a matter of fact, the division separates $V^2 + V^3$ from VII lateralis. The same mistake is reproduced in the figures of the skull of *Protopterus*.

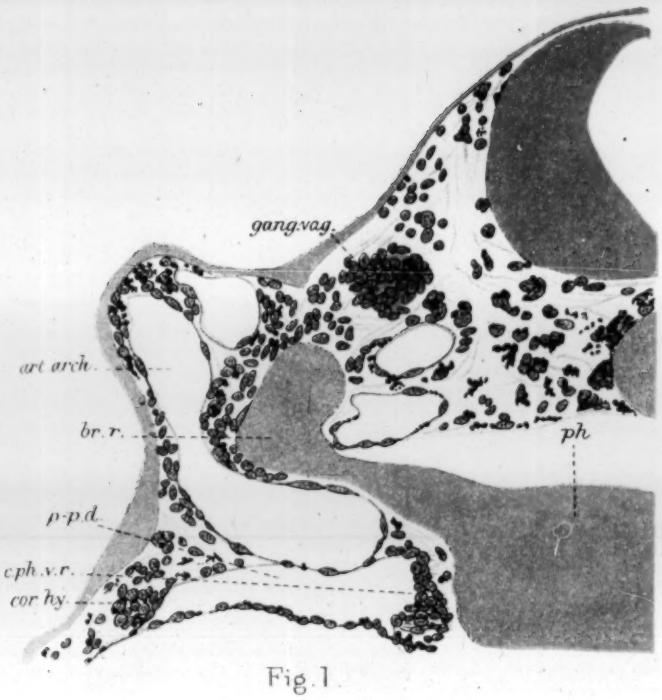

Fig. 1.

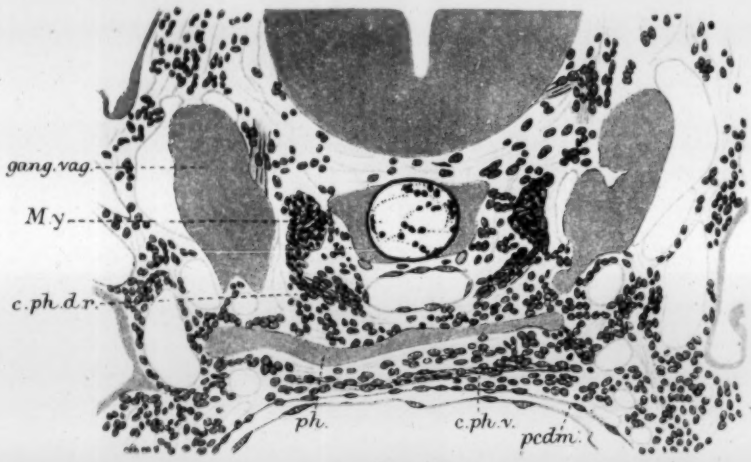

Fig. 2.

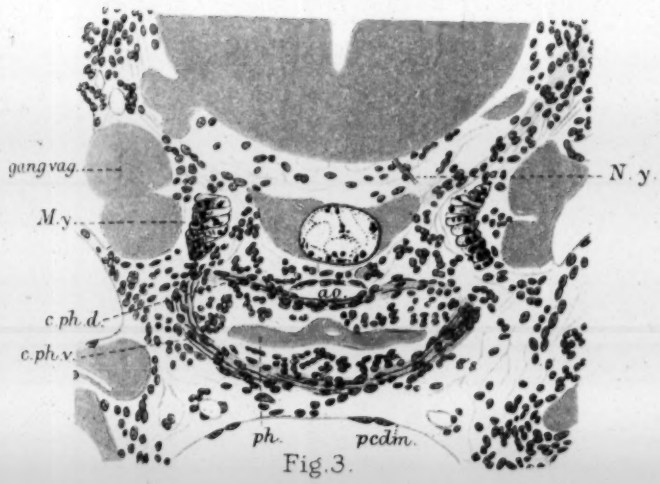

Fig. 3.

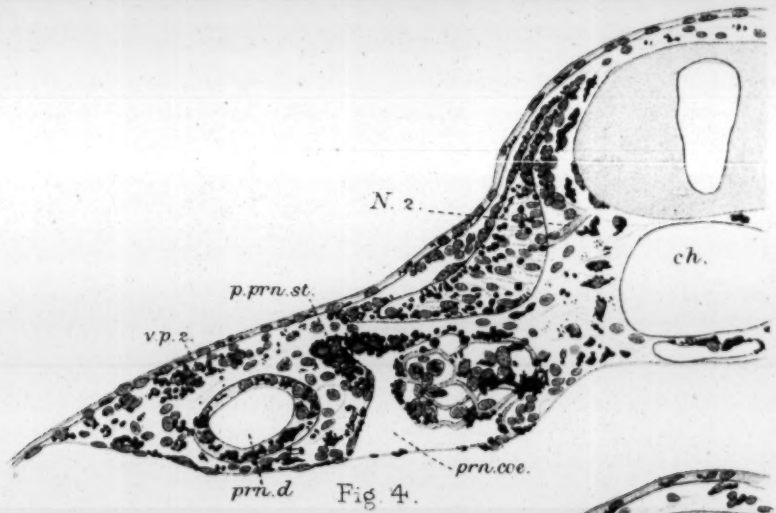

Fig. 4.

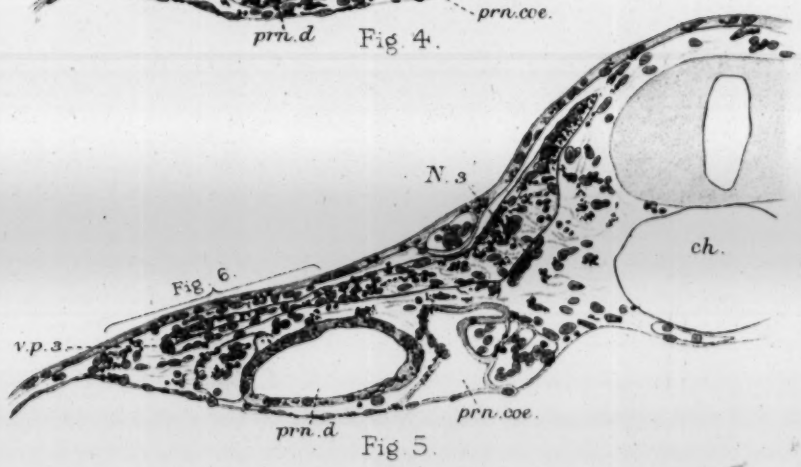

Fig. 5.

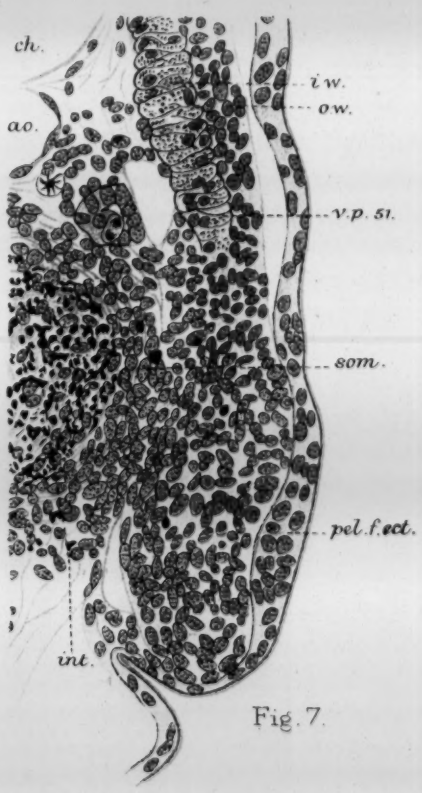

Fig. 7.

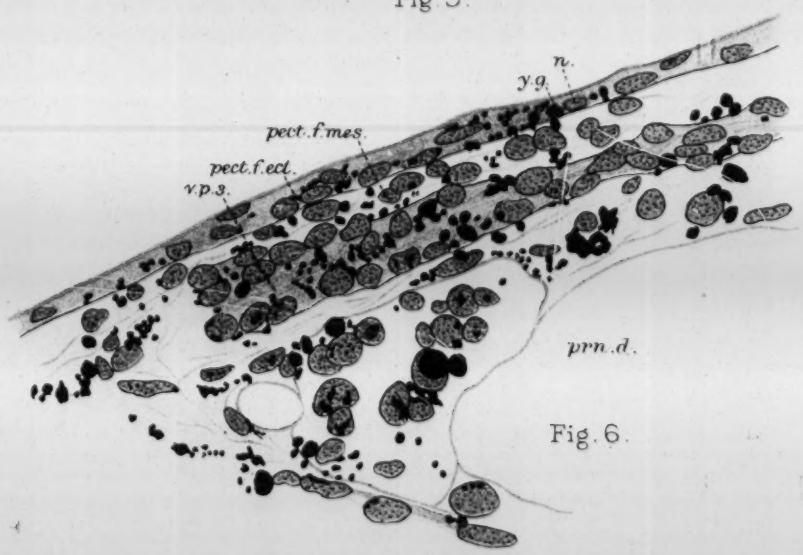

Fig. 6.

XXIV.—Scottish Tardigrada, collected by the Lake Survey. By James Murray. *Communicated by* Sir John Murray, K.C.B., etc. (With Four Plates.)

(MS. received January 2, 1907. Read February 4, 1907. Issued separately May 20, 1907.)

Introduction.

In 1905 there was published an account of the Tardigrada collected in the Scottish Lochs by the Lake Survey (6). At that date we were able to name 21 species. The subsequent work of the Survey has enabled us to add a number of species to the list.

Moreover, the wanderings of the members of the Survey over every part of Scotland offered an excellent opportunity for the study of the whole Tardigrade Fauna. A recent journey to the Orkney and Shetland Islands added much of interest to our knowledge of Tardigrada, though few of the species found were lacustrine. The work of Mr Wm. Evans in the basin of the Forth has also added much of value to our records of Tardigrada (7), (10).

Considering the large number of species now collected from all parts of the country, it is thought desirable to bring together all that is known about Scottish Tardigrada, in the hope that such a *résumé* will assist the further study of this group of animals.

The Tardigrada are now being found to be much more numerous than was long thought. A great many of the earlier species are very insufficiently described; and the more it appears that species are numerous, the more doubt attaches to the earlier descriptions. Some of these are doubtless compounded of the characters of various species which were confounded together. Many of the most important characters were neglected, under the impression that they were not sufficiently stable: the pharynx, with its system of rods, for instance, was hardly regarded before Richters, while I see no reason to suppose that the number and form of these rods is any less constant than, say, the dentition of Vertebrata.

All the Tardigrada yet found in Scotland have their ordinary habitat among moss. They appear to be generally indifferent to the situation of the moss, as the same species may be found alike among permanently moist moss, and among moss which is only intermittently moist. No doubt there are some exceptions, and certain species may affect always certain situations. Professor Richters remarks that the degree of coloration of *M. oberhäuseri* appears to depend on the exposure of the wall where they are found.

Some kinds are found in the mud of ponds and lakes when no moss may be present, but those same kinds are commoner among moss.

M. macronyx and *M. dispar* appear to be almost confined to ponds and lakes.

Of the 41 species of Tardigrada recorded for Scotland, 31 have been found in the lochs: the remaining 10 are as yet only known as moss-dwellers.

The subject is in this paper treated under the various headings—"Tardigrada of the Scottish Lochs"; "Tardigrada of Orkney and Shetland"; "Scottish Alpine Tardigrada"; and "Notes on the Genera and Species."

The Tardigrada of the Scottish Lochs.

In the previous paper on the Tardigrada of the Scottish lochs there were enumerated 21 species. Despite this considerable number of species, it must not be supposed that very many Tardigrada are normal inhabitants of permanent waters. The Tardigrada were obtained among mosses and other plants growing round the margins of the lochs; and though rightly included in the lake fauna, many of them were doubtless only casually present. The Tardigrada are most at home among mosses which are intermittently moist. Some species of *Macrobiotus* are of usual occurrence in ponds, peat bogs, and other permanently moist places. *M. macronyx* has been usually regarded as the only really aquatic species. Some similar species, which are described in this paper, seem also to be peculiar to ponds. The genus *Echiniscus* rarely occurs in ponds or lakes.

Since the previous paper appeared, ten additional species have been found at lake margins, making the total of 31 species for the Scottish lochs.

In the appended list of the 31 species it was necessary to include one or two which, there is reason to believe, were wrongly identified, as they had been recorded in the previous paper. Those doubtful or erroneous records are indicated in the list. *M. macronyx* and *M. islandicus* are not yet certainly known to occur in Britain.

There is a certain doubt whether *E. granulatus*, *E. quadrispinosus*, and *M. tuberculatus* are identical with the species described under those names, but they are certainly very close to them.

Though it is certain that 29 indubitably distinct species have been found in our lochs, a few of the determinations are open to doubt. The following table gives the distribution in the lochs so far as known.

List of Species in Scottish Lochs.

Echiniscus arctomys, Ehr. Morar, Ness, and Earn.
E. mutabilis, Murray. Morar, Ness, Earn, Tay.
E. gladiator, Murray. Morar, Ness.
E. wendti, Richters Morar, Earn, Tay.
E. reticulatus, Murray. Morar, Ness, Earn, Tay.
E. oihonnæ, Richters. Ness, Earn.
E. granulatus, Doy. Morar, Ness, Tay.
E. spitsbergensis, Scourfield. Morar, Earn.
E. quadrispinosus, Richters. Morar, Ness.
Milnesium tardigradum, Doy. Ness.
Macrobiotus hufelandi, C. Sch. Lomond, Earn, Gelly, etc.
M. intermedius, Plate. Morar.
M. echinogenitus, Richters. Morar, Ness.

M. islandicus, Richters. Ness? (record untrustworthy).
M. dispar, Murray. Tay.
M. ambiguus, Murray, Ness (egg).
M. pullari, Murray. Gryfe, Ness.
M. hastatus, Murray. Tay (egg).
M. oberhäuseri, Doy. Ness (other records doubtful).
M. ornatus, Richters. Ness (other records doubtful).
M. tuberculatus, Plate. Morar.
M. sattleri, Richters. Earn.
M. papillifer, Murray. Morar, Ness.
M. macronyx, Duj.? (All records doubtful.)
M. annulatus, Murray. Morar.
Diphascon chilenense, Plate. Ness.
D. spitzbergense, Richters. Ness.
D. angustatum, Murray. Ness.
D. scoticum, Murray. Morar.
D. bullatum, Murray. Leven (Evans).
D. oculatum, Murray. Ness.

Tardigrada of Orkney and Shetland.

The Tardigrada of these remotest northern fragments of Britain were studied during September 1906, while the lochs of these islands were being surveyed.

A large number of collections were made, at the margins of lakes, in ponds, and among moss, from every kind of situation and at all elevations, from sea-level to the tops of the highest hills.

When those collections were examined during the succeeding months, it soon became apparent that they were of the highest interest.

The first general fact of interest was that there were a number of species previously only known in more northern lands, some of them only within the arctic circle. *E. islandicus*, *M. coronifer*, *M. crenulatus*, *M. harmsworthi* are such species. All of these, except *E. islandicus*, were unknown outside the arctic circle till they appeared in Orkney or Shetland.

Another interesting fact was the occurrence of a number of peculiar species previously unknown. Such were *M. zetlandicus* and *M. orcadensis*. Several other species, discovered about the same time in Scotland, were shown, by simultaneous studies of Mr Bruce's collections, to extend into the extreme north.

A curious fact is the abundance of species of the genus *Macrobiotus*, and the extreme scarcity of *Echiniscus*. Thirteen species of *Macrobiotus* were found, and only six of *Echiniscus*. The discrepancy is greater than appears from these figures, as all but 3 or 4 of the species of *Macrobiotus* were frequent and abundant, while of the *Echinisci* only *E. arctomys* was at all frequent, *E. mutabilis* was found several times, *E. gladiator* var. *exarmatus* several times, but only in one locality, and all the others were known from single examples.

The group of species to which belong *M. coronifer*, *M. crenulatus*, and *M. harmsworthi* is only known to occur in northern lands; indeed, till the finding of these three species in Shetland, no member of the group was known outside the arctic circle, within which they have a wide distribution. This group is characterised by a crescent-shaped ridge in front of each pair of claws, the ridge often spiny or wrinkled.

Comparing the two groups of islands, as may be done by referring to the accompany-

ing table, where the records are set out in parallel columns, it appears that Shetland was more productive, giving 18 species against 10 from Orkney. Only 6 species were common to the two groups, leaving 12 peculiar to Shetland and 4 to Orkney.

Six species and one variety are as yet unknown on the Mainland of Scotland: 5 of these were in Shetland only (all from Ronas Hill), 1 in Orkney only, and 1 was common to Orkney and Shetland.

List of Species in Orkney and Shetland.

	Orkney.	Shetland.
Echiniscus arctomys, Ehr.	Rousay.	Ronas.
E. mutabilis, Murray	Hoy	Saxavord.
E. islandicus, Richters	...	Ronas.
E. gladiator, Murray (var.)	...	Ronas.
E. granulatus, Doy.	...	Mainland.
E. quadrispinosus, Richters, var.	...	Ronas.
Milnesium tardigradum, Doy.	Pomona.	Mainland.
Macrobiotus oberhäuseri, Doy.	Pomona.	...
M. zetlandicus, Murray	...	Ronas.
M. tuberculatus, Plate	...	Mainland.
M. sattleri, Richters	Pomona.	...
M. hufelandi, C. Sch.	Hoy	Ronas.
M. orcadensis, Murray	Hoy	...
M. coronifer, Richters	...	Mainland.
M. crenulatus, Richters	Pomona.	Ronas.
M. harmsworthi, Murray	...	Ronas.
M. echinogenitus, Richters	Pomona.	Mainland.
M. dispar, Murray	...	Ronas.
M. ambiguus, Murray	...	Ronas.
M. dubius, Murray	...	Ronas.
Diphascon chilenense, Plate	Pomona.	...
D. angustatum, Murray	...	Mainland.

Scottish Alpine Tardigrada (8).

The term Alpine is here used simply to denote species which have been found at a considerable elevation. It is not intended to have the restricted application which may have a use in botanical studies. The Tardigrada of the hills are separately considered, because there is reason to believe that the more rigorous climate of the mountain tops is favourable to the existence of certain arctic species, and because one or two species have only been found on the hill tops. The data for the study of our mountain Tardigrada are sufficiently meagre,—Ben Lawers has been visited twice, with encouraging results; collections from Ben Ledi, Meall nan Ptarmagan, and some other Perthshire hills have been sent to me by Mr Wm. Evans; and lastly, the highest hills in Orkney and Shetland have been visited.

Those northern peaks, Ward Hill, in Hoy, and Ronas Hill, in Shetland, though

only about 1500 feet in height, might be expected, from their high latitude, to be as alpine or arctic in character as much higher hills on the Mainland of Scotland, but this is discounted by the very mild climate enjoyed by those northern lands.

Ronas Hill was indeed very rich both in arctic and in peculiar species, but this may be attributed rather to geographical position than to climate. Remote though Shetland is from Spitzbergen and Franz Josef Land, there are numerous stepping-stones, —the Faröes, Iceland, Norway, Bear Island, etc.—between them, and the peculiar feature of Ronas Hill is its union of species from so many northern but isolated lands.

The accompanying list of hill Tardigrada, numbering 23 species, shows at a glance what a large proportion of arctic species there are on our hills. *E. islandicus*, *E. wendti*, *E. spitsbergensis*, *M. coronifer*, *M. crenulatus*, *M. harmsworthi*—all, except *E. spitsbergensis* (which is frequent on the Mainland of Scotland), only previously known from high northern lands, if not actually within the arctic circle. And the proportion of arctic species is yet higher than appears above, for *M. zetlandicus*, *M. dispar*, and *M. ambiguus*, though only recently discovered in Scotland, are known to extend into Franz Joseph Land or Spitsbergen, and Scotland is, as far as yet known, the southern limit of their range.*

List of Scottish Alpine Species.

Echiniscus arctomys, Ehr. Stuc-a-Chroin (Evans).
E. mutabilis, Murray. Ben Lawers.
E. islandicus, Richters. Ronas Hill, Shetland.
E. gladiator, Murray. Ben Lawers.
var. *exarmatus*, Murray. Ronas Hill, Shetland.
E. wendti, Richters. Ben Lawers.
E. spitsbergensis, Scourfield. Ben Lawers.
E. quadrispinosus, Richters. Ronas Hill, Shetland.
Milnesium tardigradum, Doy. Ward Hill, Hoy.
Macrobiotus oberhäuseri, Doy. Ben Lawers.
M. zetlandicus, Murray. Ronas Hill, Shetland.
M. tuberculatus, Plate. Ronas Hill, Shetland.
M. papillifer, Murray. Ben Ledi (Evans).
M. hufelandi, C. Sch. Ward Hill, Hoy, Ben Lawers.
M. orcadensis, Murray. Ward Hill, Hoy.
M. coronifer, Richters. Ronas Hill, Shetland.
M. crenulatus, Richters. Ronas Hill, Shetland.
M. harmsworthi, Murray. Ronas Hill, Shetland.
M. echinogenitus, Richters. Ben Lawers, Ronas Hill.
var. *areolatus*, Murray. Ben Lawers.
M. dispar, Murray. Ronas Hill, Shetland.
M. ambiguus, Murray. Ronas Hill, Shetland.
M. dubius, Murray. Ronas Hill, Shetland.
Diphascon chilenense, Plate. Ben Lawers.
D. alpinum, Murray. Ben Lawers.

List of all known Scottish Species.

The first list gives the distribution in Scotland, and indicates such subdivision of the genera as is possible in the present state of our knowledge. Some of the groups thus separated are undoubtedly natural; others may not be so. So many are the species now known that the subdivision of the two large genera *Echiniscus* and *Macrobiotus* will doubtless soon be necessary, but in the meantime our knowledge is too fragmentary to permit of this.

The second list gives the world distribution so far as the data at my disposal permit.

* *M. ambiguus* has been recently found in abundance, among *Thamnium lemani* collected by Prof. F. A. Forel, at a depth of 200 feet, in the Lake of Geneva.

In compiling this I am mainly indebted to RICHTERS' "Arktische Tardigraden" (19) and subsequent papers, and to LANCE's "Contribution à l'étude" (4). The distribution is given under three heads—Britain; Polar Regions; other Regions. The Tardigrade fauna of the Polar Regions has received as much attention as that of any part of the world, except perhaps Germany. Under the heading "Britain" the Orkneys and Shetlands are treated separately from Scotland, as they form important links with the Arctic Region.

The polar regions are not defined as strictly limited by the polar circles, but include Iceland in the Arctic, and all lands south of the great continents in the Antarctic.

DISTRIBUTION IN SCOTLAND.

ECHINISCUS.

A. Segment V distinct from VI, paired or single.

1. *E. arctomys*, Ehr. Perth, Inverness, Orkney, Shetland, Edinburgh.
2. *E. mutabilis*, Murray. Perth, Inverness, Edinburgh, Orkney, Shetland, St Kilda.
3. *E. islandicus*, Richters. Ronas Hill, Shetland.

B. Segments V and VI fused into one plate.

4. *E. gladiator*, Murray. Perth, Inverness.
   var. *exarmatus*, var. nov. Ronas Hill, Shetland.
5. *E. wendti*, Richters. Perth, Inverness, Edinburgh.
6. *E. reticulatus*, Murray. Perth, Inverness.
7. *E. oihonnæ*, Richters. Perth, Inverness.
8. *E. granulatus*, Doy.? Perth, Inverness, Shetland, Edinburgh.
9. *E. spitsbergensis*, Scourfield. Perth, Inverness, Edinburgh.
10. *E. quadrispinosus*, Richters?
    var. *cribrosus*, var. nov. Perth, Inverness, Lanark, Shetland.
    var. *fissispinosus*, var. nov. Peebles, Inverness.
11. *E. muscicola*, Plate? Perth.

MILNESIUM.

12. *M. tardigradum*, Doy. Perth, Inverness, Edinburgh, Orkney, Shetland.

MACROBIOTUS.

A. Eggs smooth, laid in the cast skin.

13. *M. oberhäuseri*, Doy.? Inverness, Orkney, Perth.
14. *M. ornatus*, Richters. Inverness, Perth.
    var. *verrucosus*, Richters. Inverness.
15. *M. zetlandicus*, sp. n. Inverness, Shetland.
16. *M. macronyx*, Duj.? All Scotch records doubtful.
17. *M. angusti*, sp. n. Inverness.
18. *M. annulatus*, Murray. Inverness.
19. *M. tuberculatus*, Plate. Inverness, Shetland.
20. *M. sattleri*, Richters. Perth, Orkney, Nairn.
21. *M. papillifer*, Murray. Inverness, Perth.

B. Eggs (where known) spiny, crescent in front of claws.

22. *M. coronifer*, Richters. Shetland.
23. *M. crenulatus*, Ritchters. Orkney, Shetland.
24. *M. harmsworthi* (Murray 12). Shetland.

C. Eggs spiny, no hyaline matrix.

25. *M. hufelandi*, C. Sch. Common everywhere, St Kilda.
26. *M. intermedius*, Plate. Inverness, Edinburgh.
27. *M. orcadensis*, sp. n. Orkney.
28. *M. echinogenitus*, Richters. Common everywhere.
    var. *areolatus* (Murray 12). Perth, Shetland.
29. *M. islandicus*, Richters? All Scotch records doubtful.
30. *M. dispar*, Murray. Lanark, Edinburgh, Perth, Nairn, Shetland, Uist.
31. *M. ambiguus*, sp. n. Ronas Hill, Shetland, Inverness.
32. *M. pullari*, sp. n. Renfrew, Inverness, Edinburgh.

D. Eggs spiny, spines imbedded in a hyaline matrix.

33. *M. hastatus*, sp. n. Inverness.

E. Eggs unknown.

34. *M. dubius*, sp. n. Inverness, Shetland.

DIPHASCON.

A. Pharynx round or shortly oval.

35. *D. chilenense*, Plate. Perth, Inverness, Orkney, Fife.
36. *D. bullatum*, Murray. Loch Leven (Evans).
37. *D. oculatum*, Murray. Forth Valley, Inverness.
38. *D. alpinum*, Murray. Perth.

B. Pharynx narrow, at least 1½ times as long as broad.

39. *D. spitzbergense*, Richters. Inverness.
40. *D. angustatum*, Murray. Inverness, Shetland, Perth, Uist, Fife.
41. *D. scoticum*, Murray. Inverness, Perth, Lanark, Fife, Edinburgh.

GENERAL DISTRIBUTION.

	BRITAIN.	POLAR REGIONS.	OTHER REGIONS.
1. *Echiniscus arctomys*, Ehr.	Scotland, Orkney, Shetland,	Arctic, Antarctic.	Europe, Asia, Africa.
2. *E. mutabilis*, Murray	Scotland, Orkney, Shetland.	Arctic (Spitsbergen).	Asia (India).
3. *E. islandicus*, Richters	Shetland.	Arctic (Iceland).	...
4. *E. gladiator*, Murray	Scotland.	...	Europe (Faröes).
var. *exarmatus*, Murray	Shetland.	...	...
5. *E. wendti*, Richters	Scotland.	Arctic.	...
6. *E. reticulatus*, Murray	Scotland.	...	Asia (India).
7. *E. oihonnæ*, Richters	Scotland.	Arctic.	Europe (Germany).
8. *E. granulatus*, Doy.	Scotland?	...	Europe (France).
9. *E. spitsbergensis*, Scourfield	Scotland.	Arctic.	...
10. *E. quadrispinosus*, Richters	Scotland, Shetland.	...	Europe, S. America.
11. *E. muscicola*, Plate	Scotland?	...	Europe.
12. *Milnesium tardigradum*, Doy.	Scotland, Orkney, Shetland.	...	Europe, S. America, Asia, S. Africa.
13. *Macrobiotus oberhäuseri*, Doy.	Scotland.	Arctic, Antarctic.	Asia, Europe.
14. *M. ornatus*, Richters	Scotland.	Arctic.	Europe (Germany).
15. *M. zetlandicus*, Murray	Scotland, Shetland.	Arctic (Spitzbergen).	...
16. *M. macronyx*, Duj.	Scotland?	Arctic.	Europe, America.
17. *M. angusti*, Murray	Scotland.	Arctic?	...
18. *M. annulatus*, Murray	Scotland.	Arctic.	...
19. *M. tuberculatus*, Plate	Scotland, Shetland.	Arctic.	Europe (Germany).
20. *M. sattleri*, Richters	Scotland, Orkney.	Antarctic.	Europe, Asia.
21. *M. papillifer*, Murray	Scotland.	...	...
22. *M. coronifer*, Richters	Shetland.	Arctic.	...
23. *M. crenulatus*, Richters	Scotland, Orkney, Shetland.	Arctic.	...
24. *M. harmsworthi*, Murray	Shetland.	Arctic.	...
25. *M. hufelandi*, C. Sch.	Scotland, Orkney, Shetland.	Arctic, Antarctic.	Europe, Asia, Africa, America.
26. *M. intermedius*, Plate	Scotland.	Arctic, Antarctic.	Europe, Asia, America.
27. *M. orcadensis*, Murray	Orkney.	...	...
28. *M. echinogenitus*, Richters	Scotland, Orkney, Shetland.	Arctic, Antarctic.	Europe, Asia, Africa, America.
29. *M. islandicus*, Richters	Scotland?	Arctic.	...
30. *M. dispar*, Murray	Scotland, England, Shetland.	Arctic.	Asia.

GENERAL DISTRIBUTION—*continued.*

	BRITAIN.	POLAR REGIONS.	OTHER REGIONS.
31. *M. ambiguus*, Murray . . .	Shetland.	Arctic.	Europe (Geneva).
32. *M. pullari*, Murray . . .	Scotland.	...	...
33. *M. hastatus*, Murray . . .	Scotland.	...	Europe(Switzerland).
34. *M. dubius*, Murray . . .	Scotland, Shetland.	...	...
35. *Diphascon chilenense*, Plate . .	Scotland.	Arctic, Antarctic.	Europe, Asia, America.
36. *D. bullatum*, Murray . . .	Scotland.	...	...
37. *D. oculatum*, Murray . . .	Scotland.	...	...
38. *D. alpinum*, Murray . . .	Scotland.	Antarctic.	...
39. *D. spitzbergense*, Richters . .	Scotland.	Arctic.	...
40. *D. angustatum*, Murray . .	Scotland.	Arctic.	Europe (Germany).
41. *D. scoticum*, Murray . . .	Scotland.	Arctic.	...

NOTES ON THE GENERA AND SPECIES, WITH DESCRIPTIONS OF NEW SPECIES.

Genus ECHINISCUS.

Structure.—In this genus the structures which serve for specific distinction are the number of plates, their arrangement, texture, setæ, spines, or other processes; the fringe on the last legs; the barbs on the inner or outer claws. Two characters, the eggs and the pharynx, of the greatest value in the genus *Macrobiotus*, are of little service here, being invariable.

Eggs.—In all known species they are smooth, round or oval, and they are always laid in the skin at the moult.

Pharynx.—In the majority of known species there are none of the rods so characteristic for each species of *Macrobiotus*. Professor RICHTERS has found such rods in *E. islandicus*, and I have seen them in a species not yet identified.

Legs.—The spine on the first leg, which is given as a specific character of *E. creplini* and some other species, is not distinctive. It is present in most species. Its size may be characteristic, as in *E. reticulatus*, in which it is of exceptional length. An undescribed species has similar spines on all the legs. The *fringe* on the fourth legs, found in the great majority of species, changes with age, but is believed to be of characteristic form when fully grown. The *barbs* of the inner claws, also present in most species, appear to be invariable. They are often larger in the larva. *E. arctomys* and *E. borealis* (MURRAY 12) are without them. *Straight spines* near the base of the outer claws are known only in a few species (*E. blumi*, *E. merokensis*, *E. oihonnæ*, and *E. granulatus*?). They are not invariably present in the same species. They appear to be absent in the young and to develop with age, and in one species they increase in number with age till there are three on each outer claw of the last leg (*E. granulatus*).

Plates.—Professor RICHTERS distinguishes six segments (see Plate I. fig. 4*a*, I to VI), of which I, II, III, IV, and V correspond to the brain and the four ventral ganglia.

Segment VI is regarded as all that remains of the abdominal segments of other Arthropods. Originally Professor RICHTERS considered as segment VI the middle lobe of what I have called the *lumbar* plate, but the discovery of many species having three pairs of plates has led him to modify his views. He now regards this type of structure as more primitive than the commoner type. *E. islandicus* (fig. 4*a*) is a good example of it. Segments III, IV, and V each bear pairs of dorsal plates; segment VI is three-lobed. In the commoner type of structure (Plate I. fig. 5) only III and IV bear paired plates. After IV comes a single large three-lobed plate, like segment VI of *E. islandicus*, which is regarded as being composed of V and VI, so fused together that their limits are indistinguishable. The species conforming to the more primitive type, with V and VI distinct, are *E. arctomys*, *E. mutabilis*, *E. conifer*, *E. islandicus*, and a number of other species still undescribed.

All species are easily referable to one or other of these types of structure. Minor differences consist in the subdivision of certain plates, or the intercalation of smaller plates among the larger ones. The first and second median plates are often divided transversely into two more or less distinct plates. Plates II and VI are in some species divided by both longitudinal and transverse plain bands, but the "panels" thus formed can hardly be regarded as separate plates.

Texture of Plates.—Nearly all the known species have some kind of surface markings. In many species these are granules, and it has been usual to refer to any markings as granules. There is no doubt that in many cases they are not granules, though their true nature is difficult to make out. If *Echiniscus spitsbergensis* is turned about into various positions, so that the markings may be seen in profile, it becomes evident that they do not project.

In many species the markings look like perforations, and in descriptions I refer to them as such, using the terms *cribrose* or *pitted*; but in these cases I am dealing with appearances, and am not yet satisfied as to the nature of the dots. They may be of different texture from the rest of the skin, and only become perforations when the skin is cast, yet many have this appearance during life.

A few species are reticulate on the dorsal plates.

In *E. reticulatus* the pattern is very regular, the lines separating the hexagons being merely the very slightly raised margins, the spaces themselves being depressed. The reticulation of *E. islandicus* is of another nature. The spaces are of unequal sizes, generally irregular polygons, and they are bounded by pearly dots, of unknown nature, sometimes in double or treble rows between the spaces. In both species the reticulation dies out towards the margins of the plates.

Processes.—In framing diagnoses of species, much reliance has been placed on the various dorsal and lateral spines and setæ. As superficial processes are often the most variable of characters, it may be thought that too much weight had been given to such peculiarities; and it is true that, if the processes vary in number, there is little or no other distinction between most of the earlier-described species. The distinction of

species by the spines is mechanically easy, and has been accepted as sufficient by most authorities. Professor RICHTERS requires the animal described to be mature, unless there are some striking peculiarities.

There is no doubt that the processes are remarkably constant in some species, even among those of complex and unusual armature, such as *E. oihonnæ* and *E. islandicus*. It is also known that some species, while still in the two-clawed larval stage, possess all the processes which characterise the adult.

Nevertheless there is reason to believe that the processes vary in number; and if this can be demonstrated, it will be necessary to broaden the diagnoses in accordance with the facts. If this caution is disregarded, species may be *made* almost *ad lib.*, with a repetition of the disastrous fate which has overtaken some other groups of animals, or rather the students of them.

The difficulty is greatest in dealing with the central group of species of simplest structure, all built on the same plan, with two pairs of plates, two median plates (or three, the third being rather uncertain), and V and VI joined into a single 3-lobed plate. The distinctions among species of this group rest on the variations of lateral processes (maximum number 4, excluding the head) and two dorsal processes, on the paired plates,—all of these processes, in their greatest development, being long whip-like setæ. If we suppose the suppression of one or more pairs of processes (a common accident of development), and some of the others shortened in various degrees, a great number of changes can be rung on this simple arrangement. Distinctions of texture, which might help matters, have been overlooked, and, moreover, many species of this group have never been seen mature.

Variation in the number of spines has been noticed in several species. When a pair of spines is suppressed it is difficult to prove variability, but when in a plentiful collection of animals, alike in general build and texture, sometimes one spine of a pair and sometimes both are absent, the presumption is that all belong to one species, and that the spines vary in number. *E. spitsbergensis* has a very distinct characteristic texture of the plates (though the nature of the markings, which are not papillæ, is not known). Many examples have the second dorsal process (a broad triangle as figured by SCOURFIELD) more or less elongate, and a series may be formed showing all gradations to a long seta, like the first dorsal process. Some examples are found which lack seta *b*, without other difference.

It is in a form which I here unite doubtfully with RICHTERS' *E. quadrispinosus*, as var. *cribrosus*, that the widest series of variations have been traced. This also has a characteristic texture, of unequal dots, which look like perforations, but may be of another nature, and plates II and V + VI are further crossed by plain bands, both transverse and longitudinal. This has typically all four lateral processes, after the head, as long setæ, and the dorsal processes as short curved spines. One variation shows all the lateral processes reduced to short curved spines, the second dorsal process to a broad triangle; another lacks seta *b* at one side or both; a third lacks seta *b* and

all the dorsal processes, and is the most reduced condition yet seen. Another series of variations of the same species has as its principal peculiarity the forking of seta *d*. This may be forked from the base or from some distance above it (fig. 3); the branches may be equal, or one may be a short, thick spine and the other a long seta; the seta *d* of one side may be forked and the other undivided; and lastly, as in the other series, all the processes may be reduced to spines, the second dorsal to a triangle, and the seta *b* as well as all dorsal processes may be lacking. Truly a remarkable range of variation if all really belong to one species; and if not, we have, following the old rule, a considerable number of species, all built on the same lines, and differing only by the processes. I prefer to regard the processes as somewhat variable in number.

The five commonest lateral processes, which Professor RICHTERS distinguishes by the letters *a* to *e*, are indicated by the letters in the figure of *E. islandicus* (Plate I. fig. 4*a*). Many species possess all five processes, either as setæ, spines, or knobs, and many lack all of them except the first. This first seta, *a*, between the first and second segments, is present in every known species of *Echiniscus*. The other lateral processes are also intermediate between the other segments, except *e*, which springs from the slit separating the lobes of segment VI.

Larvæ.—It is highly probable that all species of *Echiniscus* have only two claws in their earliest stage. In all species of which the larva is known this is the case. When a species is found in abundance and can be well studied, there is usually little difficulty in finding some larvæ. It is therefore curious that the two-clawed larvæ of *E. reticulatus* have never been seen, though the species is very abundant in some lochs, and individuals of various sizes have been found, some very small ones laying eggs.

Two-clawed larvæ of the undernoted species are known:—*E. arctomys*, *E. mutabilis*, *E. gladiator*, *E. islandicus*, *E. testudo*, *E. granulatus*, *E. quadrispinosus*, *E. oihonnæ*, *E. blumi*, *E. merokensis*, *E. duboisi*, *E. wendti*, as also of several species not yet described.

E. arctomys, EHR. (3).

Segment V is distinct from VI, and forms a half-ring. In *E. mutabilis*, and most of the other species which have V separate, it has a pair of plates.

The two-clawed larva has been found in Loch Morar.

E. mutabilis, MURRAY (6).

Two-clawed larva, Loch Morar.

E. islandicus, RICHTERS (18). (Plate I. figs. 4*a* to 4*c*.)

Description.—Very large; 12 main plates, 3 pairs and 3 median; V paired, first and second median each divided into two parts; VI deeply 3-lobed. Lateral processes 5; *a* and *e* very long setæ; *b*, *c*, and *d* short curved spines. Dorsal processes; short, tooth-like spines on posterior border of II, III, and IV; a pair of large broad spines on V, near the middle line. Two small spines on the lateral lobes of VI. Fringe of sharp

spines on fourth leg. Small barbs on the inner claws. Central parts of all plates with pattern of pearly dots, forming irregular reticulation (fig. 4*c*). Colour red.

Sizes,—length up to 500μ, claws 32μ, reticulations 6μ to 10μ. There is a small spine on the first leg.

Top of Ronas Hill, Shetland, September 1906.

The above diagnosis is made from the Scotch example, and agrees with Professor RICHTERS' description, except in some minor details. The small dorsal spines appear to be variable in number. Our examples had four on segment II, 8 on III, and 6 on IV. All of these, except 2 on IV, are on the margins bordering on the median plates.

The reticulation is quite different from that of *E. reticulatus*, both in the nature of the bounding lines and in their irregularity of size and form.

It is by far the largest member of the genus yet found in Scotland.

E. gladiator, MURRAY (6).

The eggs, unknown when the description was published, have been found in Loch Morar. An example 166μ in length (far from the largest size) had two eggs measuring 70μ by 58μ. A two-clawed larva 120μ long was also got in Loch Morar. An example from Ben Lawers, 200μ long, had claws 14μ long.

Hitherto only known in Scotland. I have the pleasure of reporting that Herr SELLNICK of Königsberg has recently discovered it in the Faröes.

Var. *exarmatus*, var. nov. (Plate I. figs. 5*a*, 5*b*.)

Exactly like the type, except in two characters—there is no median spine, and the barbs of the inner claws are smaller. Length 166μ.

Top of Ronas Hill, Shetland, September 1906. Though *E. gladiator* (type) was not found in Shetland, the variety was found several times. Both the variety and the type have segments III and IV with paired plates, though this is not indicated in the original figure of *E. gladiator*. The pairing is indicated mainly by the cessation of the dots. The dotting, unlike that of *E. mutabilis*, is not continued on the connecting membrane between the plates. All the median plates are small; the first and second are divided in two transversely; and all show slight appearance of being paired, most marked in the anterior part of the second median.

E. wendti, RICHTERS (16), (19).

Loch Lochy, length 260μ; the two-clawed larva Ben Lawers.

E. oihonnæ, RICHTERS (16). (Plate I. fig. 7.)

Scottish examples usually have straight barbs on the outer claws of the last legs.

In Loch Earn examples the four little lateral spinules, as in *E. spinulosus*, were seen.

E. spitsbergensis, SCOURFIELD (21).

The Scottish animal supposed to belong to this species never grows so large as I have found it in Spitzbergen moss. A variety found in Loch Earn and elsewhere differs in having both dorsal processes long spines. It approaches a variety from Franz Josef Land.

E. quadrispinosus, RICHTERS (15).

The type of this species has not been found in Scotland, but several closely related animals occur, which I think it best, in our present ignorance as to the amount of variability in the genus, to unite with *E. quadrispinosus* as varieties. The type has 5 long lateral setæ, *a*, *b*, *c*, *d*, and *e*; 4 dorsal spines, on the paired plates; the surface markings, which look like perforations, are interrupted by a plain band connecting the two slits of the lumbar plate, and also by median bands on the shoulder and lumbar plates, and some transverse bands on the shoulder plate. In addition to the 10 normal plates, it has 3 additional small plates on each side—2 between II and III, and 1 between III and IV.

Var. *cribrosus*, var. nov. (Plate I. fig. 1*a* to 1*c*.)

Exactly resembling the type in all other respects, but the three additional small plates on each side were not seen. Only the 10 normal plates (3 median). There are small barbs on all inner claws. Three eggs seen. Among tree moss, Broughton, Peeblesshire, July 1906. A modification of this variety, having all the lateral processes shorter and the second dorsal spine a short triangle, was found in Loch Morar, 1903.

Var. *fissispinosus* var. nov. Exactly like the form of var. *cribrosus* found in Loch Morar, but the lateral spine *d* is double. Also in Loch Morar, July 1906 (Plate I. fig. 2): var. *fissispinosus*, forma,—lateral process *b* lacking, *c* large, strong, and curved, *d* furcate from the base or some distance above the base; all dorsal processes lacking. This would be counted a good species but for the existence of the variety *fissispinosus*, intermediate between the form and type. In tree moss, Broughton, with the variety *cribrosus* (fig. 3): var. *cribrosus*, forma—like the form (fig. 3): but spine *c* is smaller and spine *d* is not forked. There are no dorsal processes. Top of Ronas Hill, Shetland, September 1906.

The differences between *E. quadrispinosus*, type, and the form with furcate *d* and the Shetland form, seem sufficiently great. Yet all have the same surface texture, interrupted by the same plain bands, and with the var. *cribrosus* we have such a connected series of gradations that it would seem to me impossible to separate any of the varieties as distinct species. The paired lateral processes are a principal specific character of *E. aculeatus*, PLATE, but in that species it is *c*, not *d*, which is double.

Length up to 280μ.

E. muscicola, PLATE? (13). (Plate I. fig. 6*a*, 6*b*.)

Description.—Small, red; plates 10, arrangement normal, 3 median; granules coarse, regular. Lateral processes 4 on each side, all setæ (*a*, *c*, *d*, *e*). Dorsal processes, one strong spine on each plate of first pair. Fringe on fourth legs. Strong barbs on claws.

Length 185μ (excluding the legs). Eggs large, (58μ), nearly round, red.

Monument Hill, Comrie, Perthshire, June 1905.

The number of processes corresponds with that of *E. testude* and *E. muscicola*, but their position differs from both. As the dorsal spine is over seta *c*, the correspondence is closest with E. *muscicola*, PLATE, but the lateral setæ of that species are *a*, *b*, *c*, *d*.

Genus MACROBIOTUS.

It has been thought that most of the organs which might have been used in discriminating species were too variable to permit of their use in this way, the claws alone being regarded as trustworthy characters. In consequence of this supposition most of the earlier species are insufficiently described, and are hardly recognisable; they can only be firmly established by subsequent more detailed diagnoses.

With increasing experience, faith is being established in the practical constancy of most of the structures, or at any rate it is now supposed that their variability is confined within narrow limits. If further work confirms this belief, it will have to be conceded that species are much more numerous than has hitherto been supposed.

An amount of caution in describing new species is laudable, yet too much of it may hinder the progress of knowledge.

The most different animals have been regarded by various observers as *M. hufelandi*, partly because they allowed too much for variation, and partly because they supposed there were only a few species in the genus, whereas there may be probably from 12 to 20 or upwards of common species in any district.

LANCE (4) naïvely (p. 206) discusses the improbability of the existence of *M. tuberculatus*, PLATE, merely because he hadn't found it.

The three most useful characters in framing diagnoses are, the pharynx, the claws, and the egg. Of secondary but still great importance are the teeth and the texture of the skin.

The pharynx.—The chitinous rods in the pharynx are found in three principal types. There appears to be nearly always a short, thick process attached to the end of the gullet. The differences of the three types are found in the succeeding thickenings.

The *hufelandi* type of pharnyx has in each row of thickenings two unequal rods, the first, nearest the gullet, longer, and apparently formed by the junction of two shorter rods; the second usually about half the length of the first. The second type, which

may be called the *echinogenitus* type, has three nearly equal rods, the third slightly the largest. The third type may be called the *oberhäuseri* type. In this the process attached to the gullet is very large, and there are only two other rods, which are almost exactly equal, and usually short, often as broad as long.

With each type there may be an addititional more obscure process of the end of each row. This RICHTERS aptly calls the "komma." It appears to be a reliable character, but there is some little doubt about this.

Variability of the pharnyx.—The only variation noted is in the number of rods, and appears to be a matter of age. The pharnyx is, I believe, very constant in adults, but the young have sometimes one rod less in each row. In most species the well-developed young in the egg have all the essential characters like the adult, but the young of *M. angusti* and *M. annulatus* have one long rod in place of the two rods nearest the gullet. These two rods are simply joined in the young, and become free in the adult. In the *hufelandi* type of pharnyx they are usually permanently united.

Structure of pharynx.—The true relation of the various parts of the pharynx and their mode of working was first made intelligible by ALBERT BASSE's beautiful sections, figured in his instructive "Beiträge zur Kenntnis der Baues der Tardigraden" (22).

The claws.—There are four well-marked types of claws. The *hufelandi* type has the two claws of each pair united in their lower parts, say from one-third to two-thirds of the length of the larger claw. A variety, of which *M. coronifer* is an example, has a crescent-shaped ridge, sometimes bearing a series of spines, in front of each pair of claws. The *echinogenitus* type has the claws of each pair united at the base only, or for a short distance above it; the pairs are similar, but one claw of each pair is somewhat longer. The *macronyx* type has the claws of each pair very unequal, the pairs similar, the disparity less between those of the last legs. The *oberhäuseri* type, which might also be called the *Diphascon* type, as it prevails throughout that genus, has one pair of claws slightly unequal, and joined at the base, the other pair consisting of one short claw and one very long slender claw, apparently springing from the middle of the back of the shorter claw, but movable upon it.

There is usually no difficulty in assigning a species to one of these types, but puzzling intermediate forms sometimes occur. The *oberhäuseri* and *echinogenitus* types are joined by a series of gradations.

The supplementary points near the tips of the larger claws appear to be very often two in number in the *hufelandi* type, and sometimes in the *echinogenitus* type.

The eggs.—There are also four distinct types of eggs, but they fall into two great groups—those which are normally laid in the cast skin of the animal itself, and those which are laid free from the skin. The eggs laid in the skin, which may be called the *macronyx* type, are always smooth, usually oval or elliptical, but sometimes nearly round. There are three varieties of eggs laid free,—first, the *hufelandi* type, which is round, with the surface covered with processes, generally uniform and evenly spaced over the surface (the egg may be oval [*coronifer*], and the processes may be irregular

[*islandicus*]); second, the *hastatus* type, which is round or oval, with the surface studded with rods, which are imbedded in a clear matrix, a form of egg-covering similar to that of many winter eggs of Rotifers and other animals; third, the *antarcticus* type, which is oval, without spines, viscous, and is laid free.

The eggs of *M. hastatus*, the only British species of the group which has the spines imbedded in a hyaline matrix, though it lays its eggs free from the moulted skin, yet has been found to deposit them three together in the cast skins of certain Cladocera so constantly that this seems to be a normal provision for their safety. Another species, *M. annulatus*, which lays smooth eggs in the skin, carries this skin about with it, like a sack on its back, till the eggs are hatched. Living young have been seen in the body of one species, *M. zetlandicus*; but as this species constantly lays eggs in the skin, we must suppose the living young to be the result of some mischance in development, such as inability to deposit the eggs, which would then hatch in the body.

Moulting.—Eggs of the *macronyx* type are usually all laid before the parent begins to emerge from the skin, though of course the old skin has been completely loosened before the eggs are laid. The animal in its new skin has room to move freely inside the old, and can easily turn end for end. It has been seen in many species to finally quit the old skin by simply walking out, the skin having split in the front part of the ventral side.

Eyes.—It is recognised that the presence or absence of the eye-spots is too uncertain to allow of their use as specific characters. While agreeing with this, I am inclined to think that the eye-spots are as stable as in other groups of the lower Invertebrata. In a species possessed of eyes, blind individuals may occur—it is a case of defective development merely,—but I do not expect to find the converse, viz. species normally blind, to have occasionally individuals with eyes.

Blood.—The watery fluid filling the body cavity contains numerous large nucleated corpuscles, now called fat-cells. These, commonly hyaline and colourless, may become yellow, grey, or black, doubtless in relation to the activity of their functions. In some species they are of a characteristic colour—golden brown in *M. coronifer*, paler yellow in *M. islandicus*, reddish in an Indian species, etc.

Stomach.—The stomach walls often present distinctive characters. They may be composed of very few large cells, only 6 or 8 visible in one view, or of very numerous smaller cells (*M. coronifer*). These cells often have contents of a characteristic colour—sienna-brown in *M. annulatus*, umber in *M. coronifer*, and so on. Animals are often found with the stomach of a deep blue or sometimes green colour. This colour is within the cell, and independent of the stomach contents, though perhaps chemically resulting from the nature of the food. It is not known whether it is an invariable characteristic of certain species, but there are reasons to doubt this. *M. papillifer* only occasionally has the blue granules in the stomach cells. Richters found the blue stomach in *M. islandicus*, but whether constantly I do not know. In littoral collections from Loch Ness examples with blue stomach are always abundant and belong to several species.

One of these appears to be more constantly blue than the others. This was erroneously recorded as *M. islandicus* (6), trusting to the blue colour and the pharynx. It is now known to lay smooth eggs in the skin, and is therefore quite distinct from *M. islandicus*. The blue colour is found in large granules, of nearly uniform size, densely filling the cells. The colour is sometimes modified by a distinct green tint in the most anterior and posterior cells.

Simplex forms.—No explanation has yet been offered of these curiously reduced forms. RICHTERS, without attempting to account for them, regards them as parallel forms, comparable with the various castes of bees and other sociable insects. This implies that they are permanent, and that the peculiarity continues throughout life, and this view is supported by the fact that in some species RICHTERS has seen the simplex form emerge from an egg slightly different from the typical egg of the species. In this view of their permanence I cannot concur, basing the opposite opinion on the fact that the simplification may go so far as the total disappearance of the alimentary canal in front of the stomach, with all its accessory organs. Large well-nourished animals, with stomachs full of food, and no mouth or gullet, obviously cannot have been long in that condition. I have suggested (6) that this change is correlated with moulting, and I still think that this is the general fact, though it cannot apply to the simplex forms in the egg. In view of the investigations into the encystment of *Macrobiotus* now going on in various quarters, the connection of simplex forms with moulting may have a possible meaning. The simplification which happens during encystment is carried much further than in the ordinary simplex forms, involving the loss of claws and stomach as well as pharynx. There is at least a very striking parallel between the two phenomena, and it may prove to be more. If the encystment is demonstrated to be, as among lower forms, really a kind of rejuvenescence, and if this requires the absorption of all the organs and their re-creation anew, then the simplex forms might be individuals in which the absorption had been stimulated prematurely before the moulting, which usually precedes it, or, conversely, that the moulting had been retarded.

ENCYSTMENT.

It has recently been discovered that certain species of *Macrobiotus* encyst themselves. Professor LAUTERBORN published the first note on the subject (5). The animal forms within the skin, which is loosened as for an ordinary moult, an elliptical yellow cyst, within which, in one species at any rate, it undergoes a curious metamorphosis, losing all its conspicuous organs. The process is not fully understood, and has never been completely traced. What happens next, after the reduction above referred to, is unknown. The escape of animals from cysts has been seen by Professor RICHTERS and myself, but in no case could we tell whether these animals had ever undergone reduction. I am inclined to think that these escapes have been premature, and due to stimulation by the unnatural heat of a room. In one species, *M. dispar*, recently

described in the *Zoologist* (11), the process is very complex, and an outer and an inner case are formed (see figs. 11*f*, 11 *g*). Cysts of various species are now known. *M. echinogenitus*, *M. oberhäuseri*, and a species of *Diphascon* have been found with cysts like the inner elliptical cyst of *M. dispar*. In those cases the peculiar outer case is not formed.

Professor Richters, in a recent letter, suggests that *Macrobiotus* cysts were known to Spallanzani. His figures are copied by Schultze (20).

Classification.—So numerous are the species of *Macrobiotus* now known and so varied in structure that, as a matter of convenience, it is already necessary to attempt to subdivide the genus into natural groups, eventually into distinct genera.

Any of the distinct types of pharynx, claws, or egg described in a previous paragraph might serve as a basis for subdivision. It is at present quite uncertain whether any of these types are characteristic of natural groups. A given type of one organ does not appear to be ever invariably associated with a certain type of another organ, although there are long series where two organs correspond in type. There are always some exceptions, and indeed most species could be recognisably defined merely by the combinations of the types of pharynx, claws, and egg.

We may then inquire whether it is possible to found a natural classification on the various types of one organ. There seems no reason for supposing that the various forms of claws distinguish more natural groups than the various forms of pharynx. The difference between the smooth and spiny eggs seems to point to a more profound separation of the groups producing them, since there is not only the widely different eggs, but their future is provided for in a totally different manner,—the spiny eggs being deposited and left to their fate, while the smooth eggs are enclosed in a sack formed of the cast skin of the parent.

M. oberhäuseri, Doy.? (2). (Plate IV. figs. 27*a* to 27*d*.)

Though recorded in the Tardigrada of the Scottish Lochs (6), that record cannot be trusted, as I did not then sufficiently understand the species. Having been favoured by Professor Richters with living examples and slides of the animal, a brief diagnosis can now be given. *Claws* of the type common in the genus *Diphascon*, one pair nearly equal and joined at the base, the other having one very long slender claw, movably attached to the middle of the back of the shorter claw. *Pharynx* with 3 nuts in each row—a small one attached to the gullet, and 2 larger free nuts.

The brown pigment is a very warm colour, inclining to madder; it is variable, and may be absent.

Animals with claws and pharynx as described above are frequent; one pigmented example in moss from the pier, Fort-Augustus.

An animal having the claws and pharynx of *M. oberhäuseri* was seen to hatch out of an egg found in Loch Ness, December 1906.

This egg was of the *hastatus* type. The egg is round, the hyaline layer thinner

than in *hastatus*, the processes very short round-topped rods. The egg might sufficiently fit DOYÈRE's description of "mulberry-form" but for the exceeding minuteness of those rods. Looked at from above, they look like pellucid dots (see figs. 27*a*, 27*d*).

M. sp. ? (6).

The *Macrobiotus* erroneously recorded as *M. islandicus* (6) appears to be related to *M. oberhäuseri*. It has claws of the same type, and pharynx with the same number of thickenings, but two of these are rods instead of nuts. The eggs are smooth, and four have been seen laid in the skin. The stomach cells are usually filled with dark blue granules, but these may be absent.

It appears to be distinct from any described species, but further study is needed. Common at lake margins.

M. zetlandicus, sp. n. (Plate IV. figs. 24*a* to 24*d*.)

Specific characters. — Large, brown. Teeth straight, very stout, furca of large lobes; pharynx of the *oberhäuseri* type, with all the three thickenings in each row short and broad, the second and third deeply two-lobed on outer side; claws also of *oberhäuseri* type, all large and strong, the longest with two supplementary points; eggs elliptical, laid in the skin. Eyes dark.

Length up to 580μ, claws 30μ, egg 94μ by 75μ.

Living young have been seen in the body of the parent, but as eggs are usually laid I do not think we have in this species any exception to the rule throughout the order. I rather suppose that some malformation has prevented the deposition of the eggs, which were retained till hatched.

The deeply-lobed rods distinguish it from all known species. Bog pool, Fort-Augustus, 1905; Shetland, abundant, 1906; Spitsbergen (W. S. BRUCE), 1906.

M. macronyx, DUJ. ?

All the various Scotch records for this species are open to doubt. It has been found that the animal so identified has spiny eggs (see *M. dispar*, below), and cannot therefore be *M. macronyx*. In the Forth area (10) a skin was found containing 15 eggs, and with claws like those of *M. macronyx*, but the pharynx was not seen, so the identification is not complete.

M. tuberculatus, PLATE (13). (Plate IV. figs. 24*a* to 24*c*.)

PLATE's description is very meagre and unsatisfactory. More than one form with similar tubercles is known. PLATE says there are 2 rods in the pharynx, and figures 3. A Spitsbergen form has a nut and 3 short rods, without "comma." The Shetland form has only 2 short rods and a comma. I have no doubt these are distinct species.

The example from Loch Morar was a simplex form. The claws are very divergent.

M. sattleri, Richters (15). (Plate IV. figs. 26*a* to 26*c*.)

Description of the Scottish form.—Very small. Tubercles in 8 or 9 rows on the posterior half of the body, about 4 tubercles in each transverse row, some small sharp spines like those of *M. papillifer*. Back reticulate, in polygons of various sizes, arrangement somewhat symmetrical, largest polygons central. Only simplex forms seen. Claws equal, widely divergent.

The pharynx of a precisely similar Indian form had a fixed nut and three free nuts, just as in Spitsbergen form of *M. tuberculatus*.

M. papillifer, Murray (6).

Eggs up to 6 in a skin. Stomach sometimes with blue granules.

M. annulatus, Murray (6).

When the skinful of eggs is carried, it is fixed to the centre of the top of the head, where a little cluster of globules may represent a kind of cement gland. The original figure (6) is in this respect inaccurate. Eggs sometimes 4, rarely 5.

M. angusti, sp. n. (Plate IV. figs. 25*a* to 25*d*.)

Specific characters.—Large, hyaline, with brownish stomach. Claws of echinogenitus type, united near base, one claw of each pair longer. Teeth curved, with bearers. Pharynx shortly oval, with 4 thickenings in each row—1st, a nut, joined to gullet; 2nd, 3rd, and 4th, slender rods, the middle one rather shorter. No eyes. Eggs oval, laid in the skin, 4 to 6 or more.

Length 757μ, pharynx 75μ, claws 22μ, egg 115μ by 92μ.

This large species has no very close relatives.

Bog pool near Fort-Augustus, 1904, abundant.

M. coronifer, Richters. (Plate III. figs. 22*a* to 22*c*.)

(16.) Very large: fat-cells golden-yellow. Crescent in front of claws, bearing a series of curved spines. Pharynx shortly oval, thickenings three in each row,—1st, a round nut attached to gullet; 2nd and 3rd, short rods, little longer than broad. Egg very large, golden-yellow, elliptical, closely set with weak straight-pointed spines.

The largest known Tardigrade, attaining 1 mm. in length. It was the first of that interesting group having the crescent in front of the claws, discovered by Professor Richters. As it has not yet been figured in any work in English, a short description and figure are given here. Shetland, near top of Ronas Hill; also on West Coast, few examples, size 862μ.

M. crenulatus, Richters (19).

Specific characters.—Large, hyaline or brown; teeth stout, curved; pharynx of *hufelandi* type, with long double rod, short rod, and comma in each row; claws of

hufelandi type, united more than half-way, crescent in front of claws, plain in the young, wrinkled in the adult. Supplementary points two.

Length 400μ (Spitsbergen examples up to 750μ). Scotch examples have a papillose process on each leg, not mentioned by RICHTERS. The last leg is sometimes papillose. The crescent is most distinct on the fourth legs, and, except in very large examples, only those are wrinkled. Abnormal additional claws are frequent.

Orkney (Pomona), August 1906; Shetland, Spitsbergen (BRUCE), 1906; Franz Joseph Land (BRUCE), 1897.

M. harmsworthi, MURRAY (12).

Specific characters.—Size moderate, pharynx shortly oval, thickenings 4 in each row, all nearly equal, short, 1½ times as long as broad, the first attached to the gullet, an obscure narrow "comma." Claws like those of *hufelandi*, united about half-way, supplementary points two, a crescent-shaped ridge in front of each pair. Dark eyes. Egg spiny, the spines acuminate, their bases touching, papillose.

Length, of adult 470μ, of pharynx 45μ, of young 284μ, pharynx of young 30μ.

Shetland. Spitsbergen, Franz Josef Land (BRUCE).

The egg is somewhat like that of *M. ambiguus*, but is smaller (105μ over spines) and has fewer spines.

M. hufelandi, C. SCH. (20).

Variety.—The egg figured in Scot. Alp. Tard. (8), fig. 6, is very like the type, with the spines shortened till the discoid part seems to lie on the top of a hemisphere. In Shetland many of these eggs were found with well-grown young. The pharynx is sufficiently like the type, but the second (single) rod is nearly equal to the first double rod. The end of the gullet (in the pharynx) is very much thickened. The gullet is narrower than in the type. There is a faint crescent in front of the claws of the last legs. Only one supplementary point seen on each larger claw. No eye seen.

M. intermedius, PLATE (13). (Plate II. figs. 13*a*, 13*b*.)

The characteristic egg, with processes enlarged upwards like little funnels, has been several times found in Loch Morar.

M. orcadensis, sp. n. (Plate II. figs. 10*a* to 10*e*.)

Specific characters.—Pharynx of the *echinogenitus* type, having a nut, 3 short rods, and a comma in each row; teeth curved, with bearers. Claws of *hufelandi* type, united half-way. Eyes dark. Egg small, spiny, the spines like those of *M. furcatus*, MURRAY (9), but the divided points less regularly dichotomous, having 2, 3, or many slight branches; egg shell between spines dotted.

Only known from the egg and the newly hatched young. Length of young 230μ, pharynx 26μ, claws 9μ. Egg 77μ over spines.

Nearest to *M. furcatus*, it is distinguished by the smaller egg, weaker spines, without the basal circlet, weaker teeth, etc.

Orkney, Ward Hill, Hoy, September 1906.

M. echinogenitus, RICHTERS (16). (Plate III. figs. 14*a*, 14*b*.)

Cysts of this species, Blantyre Moor. There is no outer case as in *M. dispar*; the cyst is yellow and of elliptical form, like the inner case of that species.

Var. *areolatus* (Arctic Tardigrada, 12).

An egg found in Loch Morar and on Ben Lawers appears to belong to this variety, which is very widely distributed, from Spitsbergen to India. There are areolations, round or hexagonal, between the spines of the egg; the pharynx lacks the "comma," and the claws are united for a greater distance above the base.

M. dispar, MURRAY (11). (Plate II. figs. 11*a* to 11*g*.)

Specific characters.—Large, hyaline or brown; claws of *macronyx* type, very unequal; pharynx large, shortly oval, rods of *hufelandi* type, viz. nut, long double rod, shorter single rod; furca of tooth very large; dark eyes; egg spiny; spines short, sharp cones, standing a little apart.

Length up to 600μ, pharynx 80μ, egg 90μ over the spines.

There are usually two dorsal conical processes between the third and fourth legs (fig. 11*a*), but these are very variable in size and may be obsolete. The egg is not distinguishable from that of *M. pullari*, described in this paper, though that species has quite different claws and pharynx.

M. dispar lives in ponds and lakes. It undergoes a curious metamorphosis, first casting its skin, then forming an *outer case* (fig. 11*g*) and an *inner case* (fig. 11*f*), within which it undergoes further changes which have not yet been completely traced.

Localities.—Nerston Quarry, near Glasgow, 1904; Loch Tay, 1905; ponds near Edinburgh (EVANS); pond at Nairn; North Uist; Ronas Hill in Shetland; Askomb Bog, near York; Spitsbergen, and Franz Josef Land.

It is seen to be widely distributed in Britain and to range far north. Of its southern range we have no knowledge. It is supposed to strongly resemble *M. macronyx*, which has, however, a quite different egg, and it is possible that some of the records of *M. macronyx* may refer to this species. It is closely related to *M. ambiguus*, described in this paper, which has also a spiny egg, but of different form.

A *Diphascon-form* of this species, with elongate gullet, was found near Edinburgh (EVANS).

M. ambiguus, sp. n. (Plate II. figs. 9*a* to 9*d*.)

Specific characters.—Large, hyaline; claws of *macronyx* type, very unequal, those of last legs less so; pharynx large, shortly oval, of *hufelandi* type—a nut, a long

double rod, and a single shorter rod in each row of thickenings. Egg spiny, spines pretty large, close together, acuminate. Teeth curved, with very large furca.

Length, of adult 430μ, claws of young just hatched 24μ, of pharynx of young 35μ, diameter of egg over spines 130μ.

The adult is hardly distinguishable from *M. dispar*, but the egg is quite different, and more resembles that of *M. echinogenitus*, while it is chiefly distinguishable by its larger size from that of *M. harmsworthi*, recently discovered in Franz Josef Land, and now known to be in Shetland.

Ronas Hill, Shetland, September 1906. Spitsbergen (Bruce), 1906.

M. pullari, sp. n. (Plate II. figs. 8*a* to 8*c*.)

Specific characters.—Large, brown; claws of *echinogenitus* type, joined at base only, supplementary points strong; teeth stout, curved; pharynx of *hufelandi* type, viz. with nut, long double rod, and shorter single rod in each row, and no "comma." Eggs spiny, round; spines short, sharp cones standing a little apart, smooth.

Length up to 570μ, pharynx 48μ long. The dark colour is arranged in longitudinal and transverse bands as in *M. oberhäuseri*, but the colour is different. The eggs are very often laid all at one time, and are found adhering in clusters. A whole "clutch" of them is sometimes accidentally included in the cast skin, and oval eggs are not rare. The round egg is not distinguishable from that of *M. dispar*, and measures 75μ over the spines, the oval egg measuring 90μ long diameter over spines.

Localities.—Gryfe Reservoir, near Greenock; Loch Ness; Forth area (Evans).

Similar eggs are known from various countries, but the identity of form of those of *M. pullari* and *M. dispar* makes it impossible to identify from eggs alone.

The species is named in memory and honour of Frederick Pullar, who with Sir John Murray began the systematic survey of the Scottish Lochs.

M. islandicus, Richters (18).

The records under this name (6) proving to be erroneous, it is doubtful if the species exists in Britain. Eggs with the peg-like processes have been found, but never with sufficiently developed young.

M. hastatus, sp. n. (Plate III. figs. 18*a* to 18*d*.)

Specific characters.—Small; claws of *echinogenitus* type, or a little inclined towards the *oberhäuseri* type, claws joined near the bases, one of each pair longer, and one long claw larger than the other, pharynx of *oberhäuseri* type, with nut joined to the gullet, and two equal rods, twice as broad as long, in each row. Egg spiny, each spine in optical section like a fleur-de-lis, the spines imbedded in hyaline matter, from which only the central spike of the fleur-de-lis projects.

Diameter of egg over spines 70μ. The eggs are round or oval, and were found in large numbers, always three together, in the cast shells of *Alonella nana*. This

happened so constantly that I suppose such shelter is deliberately sought for the eggs, though the selection of the shells of *Alonella nana* is probably only due to their great abundance.

Bog pool at Fort-Augustus, 1904. Loch Tay. Also collected in Switzerland by Dr Chas. Linder.

M. dubius, sp. n. (Plate III. figs. 17*a* to 17*c*.)

Specific characters.—Size moderate. Pharynx elliptical, somewhat narrow, of the *hufelandi* type; long rod apparently formed by the junction of two rods, of which the second is much shorter. Claws of *echinogenitus* type, one of each pair longer. Hyaline.

Size 312μ, no eyes. Egg unknown. Saxavord Hill, Unst, Shetland, September 1906; bog pool at Fort-Augustus, November 1906.

Macrobiotus, sp.? (Plate II. figs. 12*a*, 12*b*.)

The egg erroneously recorded as that of *M. coronifer* (8) has not yet been identified, but is undoubtedly distinct from any species yet named. It agrees with *M. coronifer* in the oval form and small weak spines, but has, as Richters points out, nothing else in common with it.

Diphascon.

The genus *Diphascon* now rests upon a very slight foundation. The elongated flexible gullet, on which the genus was founded by Plate, is a character shared by various species of *Macrobiotus*. In *Macrobiotus* this character is abnormal or exceptional; in *Diphascon* it is believed to be normal and permanent. I thought to distinguish a peculiar *Diphascon* type of claw (9), and it is true that all the species known have claws of one type, but it is the type found in *Macrobiotus oberhäuseri*.

The genus can therefore only be defined as having claws of the *oberhäuseri* type, and normally possessing a more or less elongated and flexible gullet. So far as known, the eggs are smooth and are laid in the skin. Eyes are present in one species only. In many species the pharynx is narrow and elongate, which is never the case with *Macrobiotus*, which has the pharynx in all known species shortly oval or roundish. The elongate pharynx cannot be made a generic character, as one or two species have it nearly round. Simplex forms occur.

Professor Richters also expresses little faith in this genus, one species of which, *D. spitzbergense*, he has described. Admitting the slight stability of the genus, and turning to the consideration of the described species, those appear to be all sufficiently distinct forms, even if we admit that the elongate gullet may be an abnormal development.

One feature alone sufficiently distinguishes the species of *Diphascon* from the great

majority of the species of *Macrobiotus*, viz. the claws of the *oberhäuseri* type. Though there is reason to believe that the genus *Macrobiotus* contains many forms having this type of claw, few such species have yet been described.

The species of *Diphascon* need, therefore, only be compared with *M. oberhäuseri*, and species (if any) closely related to it. Those having the narrow pharynx are far removed from any known *Macrobiotus*, and of the other species only one (*D. oculatum*) has the pharynx of the *oberhäuseri* type. That species is sufficiently distinguished from *M. oberhäuseri* by several characters—the lack of the brown pigment, the teeth of quite different form, etc.; the other species are quite distinct in the various details of the pharynx, always associated with *oberhäuseri* claws, even if the distinction of *Macrobiotus* and *Diphascon* breaks down.

For convenience, an artificial subdivision of the genus may be made into—A, pharynx narrow, and B, pharynx round or very shortly oval.

D. scoticum, Murray (7). (Plate III. fig. 19.)

The pharynx has the same number of rods as Richters' *D. spitzbergense* (16), but according to his figure in the "Fauna Arctica" the arrangement is different. He shows the middle narrow rod as the longest, whereas our species has the last narrow rod longest. A more important distinction is the narrow gullet of *D. scoticum*.

D. alpinum, Murray (8). (Plate III. fig. 15.)

The pharynx is intermediate between the round and elongate types, but may be classed with the latter, as it is $1\frac{1}{2}$ times as long as broad, or slightly longer than that.

D. bullatum, Murray (7). (Plate III. fig. 21.)

The blunt tubercles recall *M. tuberculatus*, Plate, but there is no other resemblance.

D. oculatum, Murray (10). (Plate III. fig. 16.)

Only known as a moss-dweller till recently discovered in Loch Ness.

D. angustatum, Murray (6).

A simplex form has been found near Edinburgh and at Killin.

Milnesium.

Within this genus no variation from the typical structure has been observed of specific value, and I agree with Professor Richters in uniting the two described species. The only variation which I have noticed is in the number of points to the shorter claws. In some districts there appear to be constantly three points to these claws. In Scotland they are variable, and we may find from one to three points, not only in different individuals from one district, but in one individual we may find all three conditions. The

long claws have very fine supplementary points, which are sometimes difficult to distinguish. The eggs are laid in the skin, and are smooth. I have seen 2 and 3 eggs. Professor RICHTERS has seen as many as 15.

M. tardigradum, DOY. Length 430μ, pharynx 60μ, eggs 120μ by 85μ.

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EXPLANATION OF PLATES.

It is desirable that all the figures of the complete animals should be drawn to the same scale, so that the relative sizes can be easily seen, and this has been done in most cases, but so diverse in size are various species that the largest species had to be drawn to a smaller scale in order to include them in the same plates with the smaller ones.

In Plate III. *M. coronifer* is drawn to a much smaller scale than the others, and so in Plate IV. *M. angusti* is only magnified about half as much as the small species in the corners.

The details are not drawn to any uniform scale.

Plate I.

1*a*. *Echiniscus quadrispinosus*, Richters, var. *cribrosus*, var. nov.
1*b*. „ „ outer and inner claws.
1*c*. „ „ portion of surface of plate.
2. „ „ var. *fissispinosus*, var. nov.
3. „ „ „ „ reduced form.
4*a*. *E. islandicus*, Richters, showing segments I to VI, and lateral processes *a* to *e*.
4*b*. *E. islandicus*, Richters, inner claw.
4*c*. „ portion of reticulation of plates.
5*a*. *E. gladiator*, Murray, var. *exarmatus*, var. nov.
5*b*. „ inner claw.
6*a*. *E. muscicola*, Plate ?
6*b*. „ inner claw
7. *E. oihonnæ*, Richters, outer and inner claws.

Plate II.

8*a*. *Macrobiotus pullari*, sp. n., young emerging from egg.
8*b*. „ „ pharynx.
8*c*. „ „ claws.
9*a*. *M. ambiguus*, sp. n. Egg.
9*b*. „ pharynx.
9*c*. „ claws of last legs.
9*d*. „ claws of other legs.
10*a*. *M. orcadensis*, sp. n., pharynx.
10*b*. „ egg.
10*c*. „ three processes of the egg.
10*d*. „ furca of tooth.
10*e*. „ claws.
11*a*. *M. dispar*, Murray.
11*b*. „ claws of last legs.
11*c*. „ claws of other legs.
11*d*. „ egg.
11*e*. „ furca of tooth.
11*f*. „ outer and inner cases of cyst.
11*g*. „ outer case, showing stumps of limbs.
12*a*. *Macrobiotus*, egg of unknown species.
12*b*. „ process of the egg.
13*a*. *M. intermedius*, Plate. Egg.
13*b*. „ process of the egg.

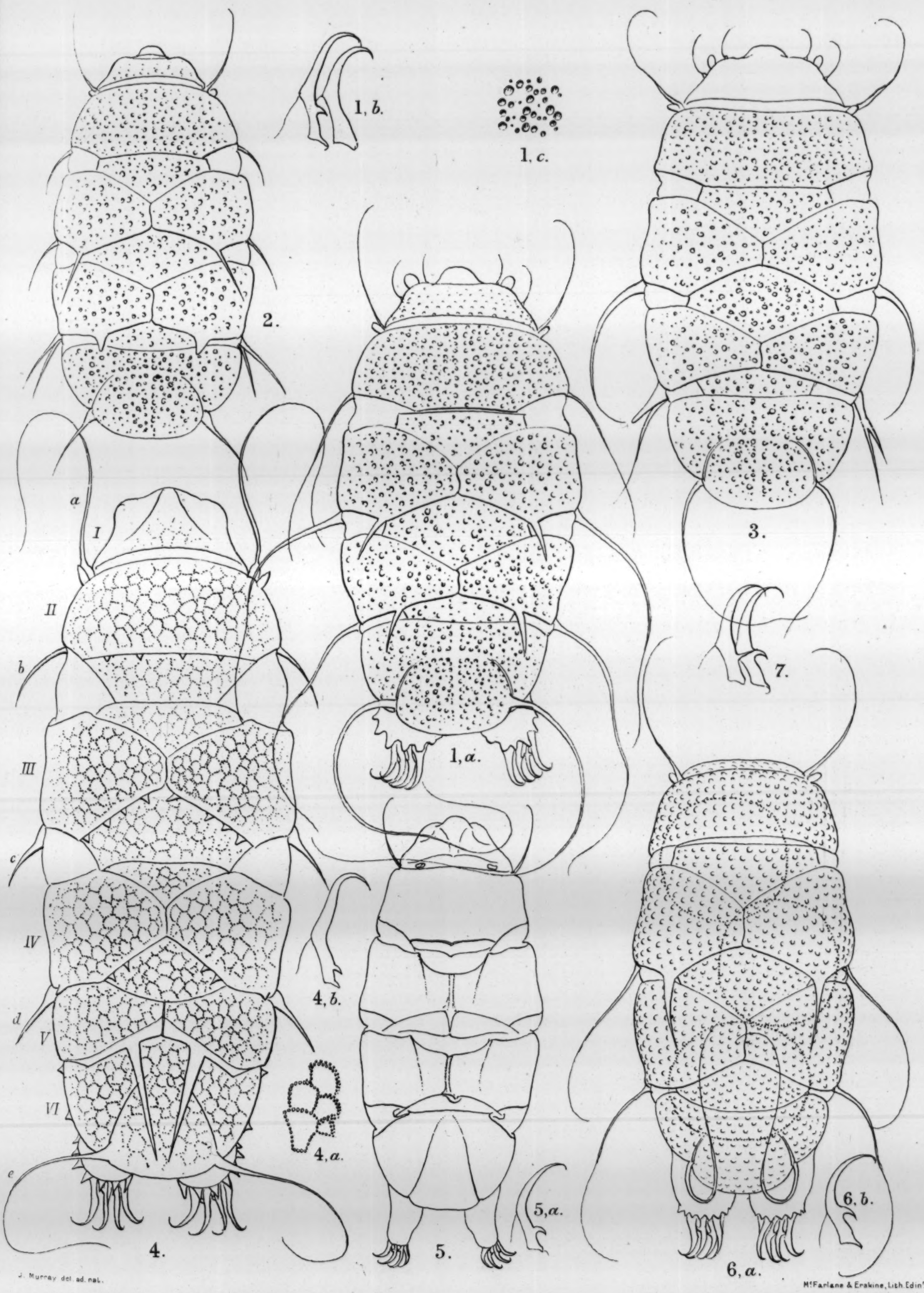
Plate III.

14*a*. *Macrobiotus echinogenitus*, Richters. Pharynx.
14*b*. „ „ claws.
15. *Diphascon alpinum*, Murray. Pharynx.
16. *D. oculatum*, Murray. Pharynx.
17*a*. *M. dubius*, sp. n.
17*b*. „ pharynx.
17*c*. „ claws.
18*a*. *M. hastatus*, sp. n. Three eggs in *Alonella* skin
18*b*. *M. hastatus*, pharynx.
18*c*. „ claws.
18*d*. „ some processes of the egg.
19. *Diphascon scoticum*, Murray. Pharynx.
20. *M. hufelandi*, C. Sch. Pharynx.
21. *Diphascon bullatum*, Murray.
22*a*. *M. coronifer*, Richters.
22*b*. „ pharynx.
22*c*. „ claws.

PLATE IV.

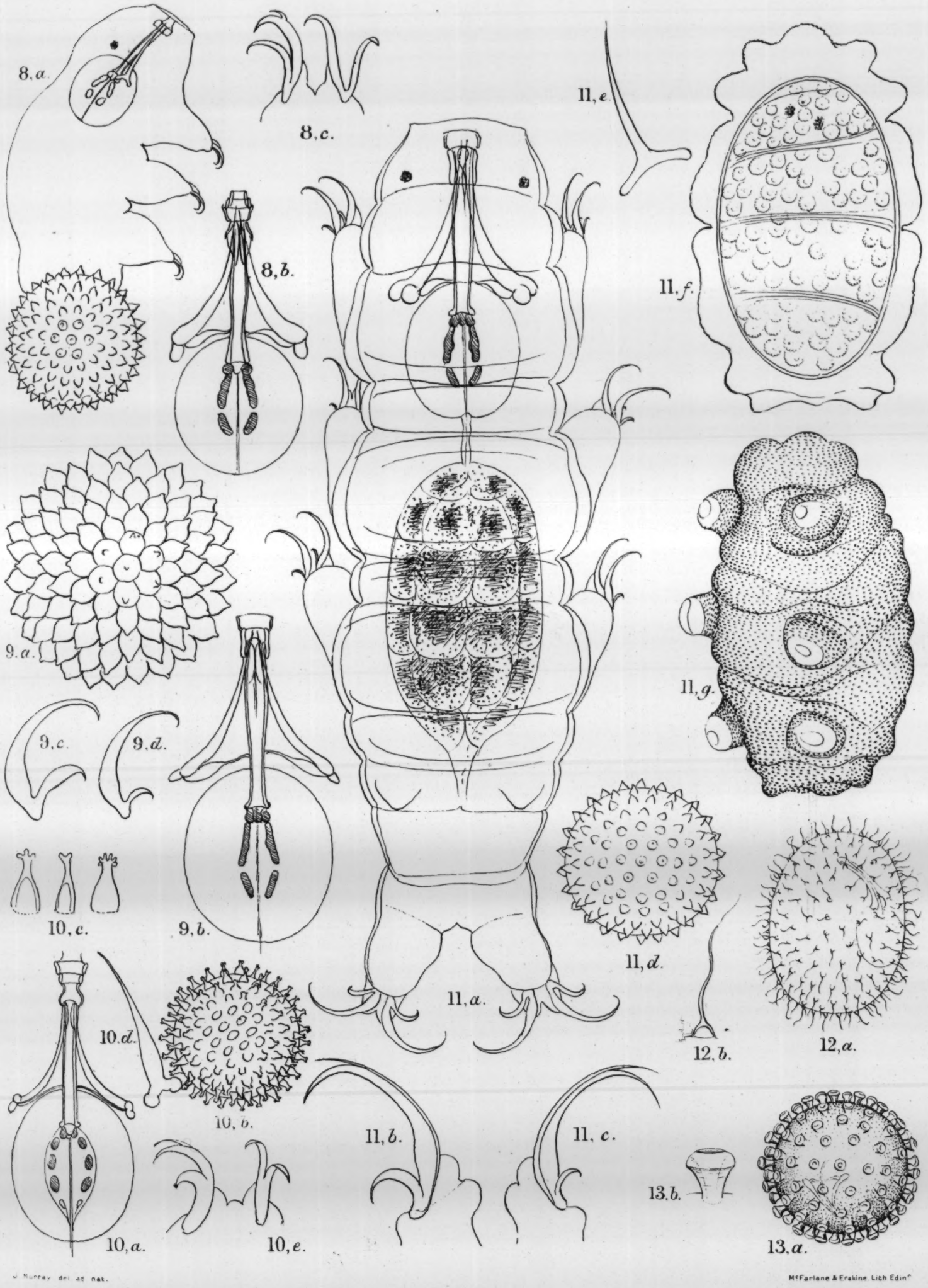
23*a*. *Macrobiotus tuberculatus*, Plate.
23*b*. ,, ,, claws.
23*c*. ,, ,, pharynx.
24*a*. *M. zetlandicus*, sp. n., pharynx.
24*b*. ,, claws.
24*c*. ,, furca of tooth.
24*d*. ,, egg.
25*a*. *M. angusti*, sp. n.
25*b*. ,, egg.
25*c*. ,, pharynx of young in the egg.
25*d*. *M. angusti*, claws.
26*a*. *M. sattleri*, Richters.
26*b*. ,, pharynx.
26*c*. ,, claws.
27*a*. *Macrobiotus*, sp.? near *M. oberhäuseri*, Doy. Young emerging from egg.
27*b*. ,, pharynx.
27*c*. ,, claws.
27*d*. ,, portion of egg, showing the processes.

MURRAY: SCOTTISH TARDIGRADA.—PLATE I.



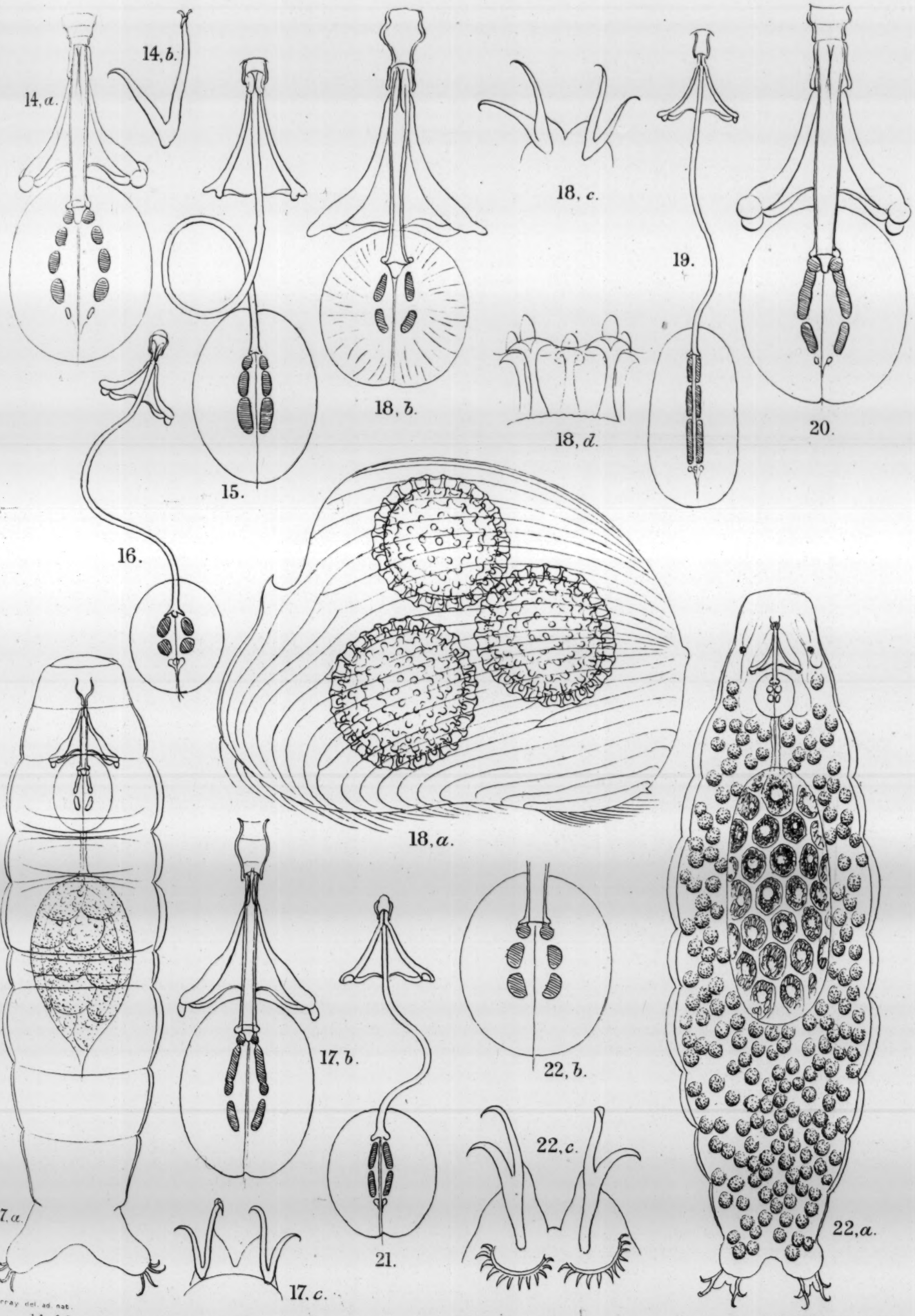
1-3, ECHINISCUS QUADRISPINOSUS, Richters ? VARIETIES. 4, E. ISLANDICUS, Richters.
5, E. GLADIATOR, Murray, var. EXARMATUS, var. nov. 6, E. MUSCICOLA, Plate ? 7, E. OIHONNÆ, Richters.

MURRAY: SCOTTISH TARDIGRADA.— PLATE II.



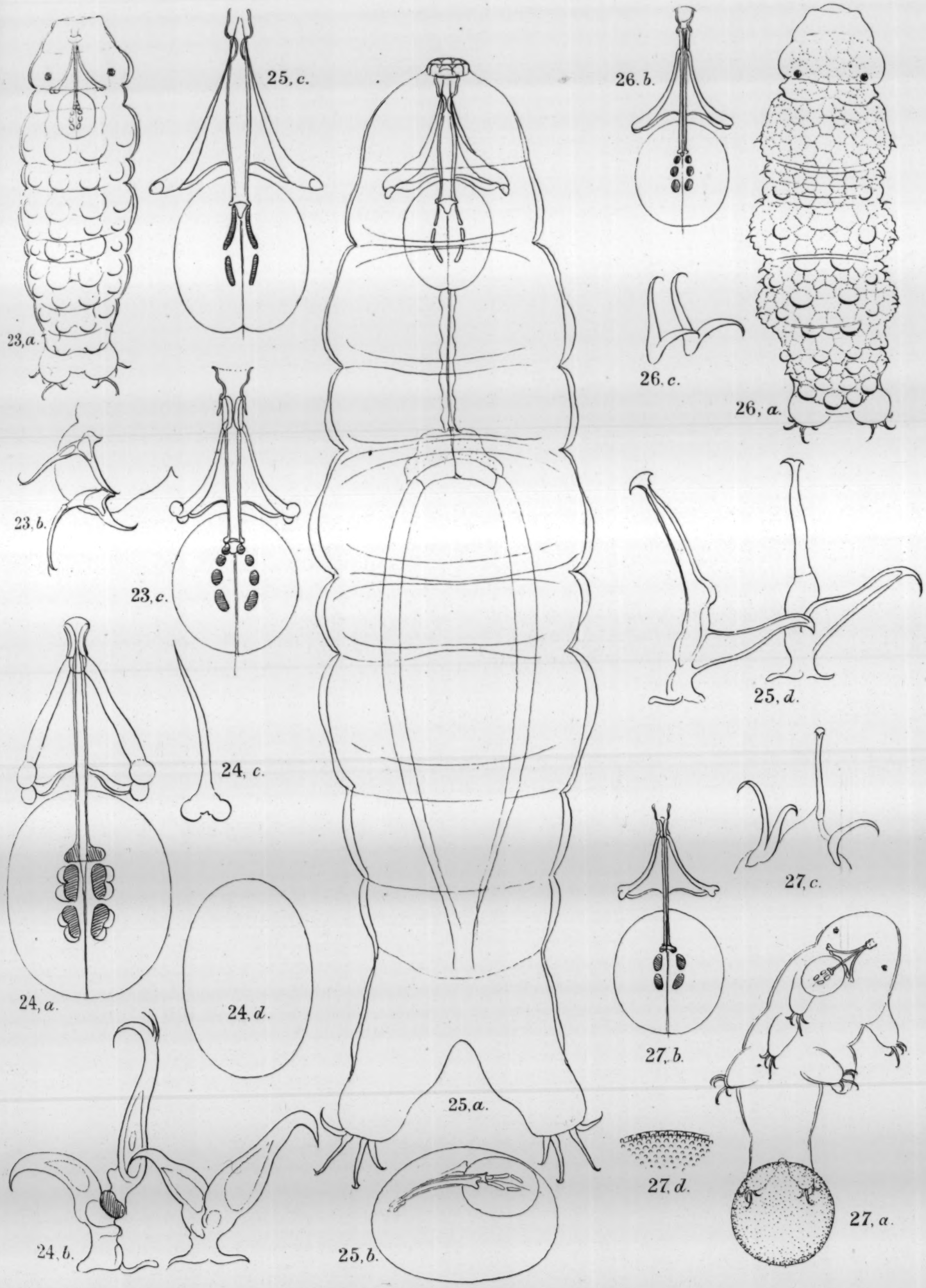
8, MACROBIOTUS PULLARI, n. sp. 9, M. AMBIGUUS, n. sp. 10, M. ORCADENSIS, n. sp.
11, M. DISPAR, Murray. 12, MACROBIOTUS, sp? 13, M. INTERMEDIUS, Plate.

MURRAY: SCOTTISH TARDIGRADA.—PLATE III.



14, MACROBIOTUS ECHINOGENITUS, Richters. 17, M. DUBIUS, n. sp. 18, M. HASTATUS, n. sp.
20. M. HUFELANDI, C. Sch. 22, M. CORONIFER, Richters. 15, DIPHASCON ALPINUM, Murray.
16, D. OCULATUM, Murray. 19, D. SCOTICUM, Murray. 21, D. BULLATUM, Murray.

MURRAY: SCOTTISH TARDIGRADA.—PLATE IV.



J. Murray del. ad. nat.

McFarlane & Erskine, Lith. Edin.r

23. MACROBIOTUS TUBERCULATUS. Plate. 24. M. ZETLANDICUS, n. sp. 25. M. AUGUSTI, n. sp.
26. M. SATTLERI, Richters. 27. M. OBERHÄUSERI, Doy ?

XXV.—Arctic Tardigrada, collected by Wm. S. Bruce. By James Murray.

Communicated by William S. Bruce. (With Two Plates.)

(MS. received January 11, 1907. Read February 21, 1907. Issued separately July 6, 1907.)

These notes on Arctic Tardigrada embody the results of an examination of quantities of moss collected by Mr William S. Bruce on his various expeditions to the Arctic Regions.

While studying the Tardigrada of the Scottish lochs, I wished to compare our Tardigrade fauna with that of more northern lands, as it was thought that, considering the geographical position of Scotland, its fauna might have some relation with that of those lands. Mr Bruce was kind enough to put all his available material at my disposal.

The various expeditions to the North in which Mr Bruce took part cover a period of ten years, from 1896 to 1906. They are:—The Jackson-Harmsworth Polar Expedition, 1896 and 1897; Mr Andrew Coats' Expedition to Novaya Zemlya, Wiche Islands, and Barent's Sea, 1898; H.S.H. The Prince of Monaco's Expedition, Spitsbergen and North Polar Regions, 1898; H.S.H. The Prince of Monaco's Expedition, Spitsbergen and North Polar Regions, 1899; H.S.H. The Prince of Monaco's Expedition, Spitsbergen, 1906.

The material collected on the earlier expeditions was all preserved in spirit, and its use was limited to the identification of adult examples. The moss collected in the 1906 expedition was of especial value, as, by previous arrangement with Mr Bruce, the collections were made with a view to the study of the microfauna. Mr Bruce collected the moss just before departing for the South at the end of August, and I was thus enabled to examine it in the fresh condition within a month afterwards. In this way I could study the animals when alive, by which the structures of the various organs can be better made out than in contracted specimens. The chief advantage of having the fresh moss was, however, that the young could be watched issuing from the eggs, and thus the identity of certain eggs with the adult animals established.

There is no part of the world the Tardigrada of which have received so much attention as Spitsbergen, except Germany. The other parts of the Arctic Regions visited by Mr Bruce appear to be virgin soil as regards the study of the Tardigrada, except Bear Island, from which 1 species, *M. ornatus*, was known.

The collections examined were from Bear Island, Spitsbergen, Franz Josef Land, Novaya Zemlya, and Kolquev, and in all but the last named some Tardigrada were obtained. Very few species were found in Bear Island and Novaya Zemlya, but the

collections from Spitsbergen and Franz Josef Land were very rich, and included many species not previously recorded from the Arctic Regions, and several new to science.

The anticipation that the Tardigrade fauna of Scotland would show some distinct relation to that of the Arctic Regions was borne out by the results of our comparative studies. It was already known that in the Crustacea of the plankton of the Scottish lochs there was a very conspicuous Arctic element. As the Tardigrada are not swimmers in open waters, however, the conditions governing their distribution are probably quite different from those affecting the plankton Crustacea.

Even on the mainland of Scotland there were several species of Tardigrada only previously known in the Arctic Regions, such as *Echiniscus spitsbergensis*, *E. wendti*, *E. oihonnæ*, *Macrobiotus echinogenitus*; but it was only when the Shetland Islands were visited that we learned how extensive was the correspondence between Scotland and the most northern lands known.

Including several species which were discovered in Shetland, there are now 14 species known which are common to Scotland and one part or other of the Arctic Regions and are unknown elsewhere.

No doubt, when the Tardigrada of other countries are better known, it will be found that many of those species are not restricted to northern lands. Already it is known that *M. echinogenitus* has an almost world-wide range, and *E. mutabilis* also ranges far in more southern lands; but in the present state of our knowledge the close correspondence between Scotland, Spitsbergen, and Franz Josef Land is remarkable.

In all Mr Bruce's collections 28 species of Tardigrada were identified and 4 others were studied. Three new species and two new varieties are here described.

Spitsbergen.

Previous to the publication of Scourfield's short list of Tardigrada in 1897 (15), the only record of a Spitsbergen Tardigrade is that of Goës, who in 1862 recorded a species of *Macrobiotus* somewhat doubtfully as *M. dujardinii*, Doy.

Scourfield found 6 species in moss collected by Dr J. W. Gregory during Sir W. Martin Conway's Expedition in 1896 (15). There were 3 known species:—*Echiniscus arctomys*, Ehr., *Macrobiotus hufelandii*, C. A. S. Schultze, and *M. tuberculatus*, Plate; 1 new species, *E. spitsbergensis*; and 2 which were not identified. One of these, according to Scourfield's notes, would appear to have some resemblance to *M. sattleri* and *M. papillifer*; the other, with narrow pharynx, is doubtless a *Diphascon*, very probably *D. spitsbergensis*, Richters.

Schaudinn (13) in 1901 describes 1 new species, *E. spiculifer*.

Richters, who examined moss collected on Wendt's Expedition, published in 1903 a preliminary list (11) and in 1904 a fuller list (12) comprising 16 species, most of which were previously unknown in Spitsbergen and 7 were new to science.

With these additions there were, according to RICHTERS' summary in *Fauna Arctica* (12), 19 species of Tardigrada recorded for Spitsbergen.

In Mr BRUCE's collections I have found 22 species. As 12 of these have not been previously recorded for Spitsbergen, the list of species now numbers 31. Two of the species are new to science, and 7 are species recently discovered in Scotland.

A curious feature in all Mr BRUCE's collections from Spitsbergen is the scarcity of animals of the genus *Echiniscus* and the abundance of species of *Macrobiotus*. Only 2 species of *Echiniscus* were found, and 15 of *Macrobiotus*. This is the more remarkable as there were already 6 species recorded for Spitsbergen, and in Mr BRUCE's collections from Franz Josef Land there were also 6 species of *Echiniscus*. There were 5 species of *Diphascon* observed.

LIST OF SPITSBERGEN SPECIES (BRUCE COLLECTION).

	Prince Charles Foreland.	Recherche Bay.	Red Bay.
Echiniscus arctomys, Ehr.			×
E. mutabilis, Murray	×		
Macrobiotus oberhäuseri, Doy.	×		
M. zetlandicus, Murray	×		
M. ornatus, Richters			×
M. tuberculatus, Plate	×		
M. tetradactylus, Greeff	×		
M. hufelandii, C. Sch.	×	×	
M. intermedius, Plate	×		
M. echinogenitus, Richters	×		
var. *areolatus*, var. nov.			×
M. dispar, Murray	×		
M. ambiguus, Murray	×		
M. crenulatus, Richters	×		
M. harmsworthi, sp. n.	×		
M. arcticus, sp. n.	×		
M. islandicus, Richters?	×	×	
M. pullari, Murray	×		
Diphascon chilenense, Plate	×		
D. alpinum, Murray	×		
D. spitsbergense, Richters	×		
D. scoticum, Murray	×	×	
D. angustatum, Murray		×	

FRANZ JOSEF LAND.

The collections from Franz Josef Land were more numerous than those from the other Arctic lands visited by Mr BRUCE, and represented a greater variety of situation, from ponds nearly at sea-level to moss growing on an old walrus skull found on a raised beach some 400 feet above sea-level.

Tardigrada were abundant in those collections, and the number of species found (19) was nearly as great as in Spitsbergen. There were besides 2 yet undescribed species.

As compared with Spitsbergen, the various genera were represented in very different proportions. There were 6 species of *Echiniscus*, 10 of *Macrobiotus*, and 3 of *Diphascon*.

The Tardigrada of Franz Josef Land and Spitsbergen do not differ materially: 15 species are known to be common to the two groups, leaving 16 which are known in Spitsbergen and not in Franz Josef Land, and 4 which are known in Franz Josef Land and not in Spitsbergen.

As all the Tardigrada of Franz Josef Land, except only *Echiniscus borealis*, are already known from some other countries, we may expect to find a still closer correspondence between Spitsbergen and Franz Josef Land when the fauna of the latter shall become better known.

List of Franz Josef Land Species (Bruce Collections).

	Carpenter's Rock.	Cape Mary Harmsworth.	Cape Gertrude.	Cape Forbes.	Walrus Skull.	Ponds at Elmwood.
Echiniscus arctomys, Ehr.		×	×			
E. mutabilis, Murray			×			
E. wendti, Richters		×	×			
E. spitsbergensis, Scourfield			×			
var. *spinuloides*, var. nov.			×			
E. borealis, sp. n.		×				
E. muscicola, Plate				×		
Macrobiotus annulatus, Murray	×					×
M. augusti, Murray	×	×				
M. hufelandii, C. Sch.				×		
M. intermedius, Plate	×					
M. echinogenitus, Richters	×	×	×	×		
var. *areolatus*, var. nov.	×	×				
M. dispar, Murray		×			×	
M. ambiguus, Murray	×					
M. crenulatus, Richters			×			
M. harmsworthi, sp. n.		×				
M. arcticus, sp. n.		×				
Diphascon spitsbergense, Richters	×					
D. scoticum, Murray			×			
D. angustatum, Murray	×					

Novaya Zemlya.

There were only a few collections available from one spot in Novaya Zemlya—Kostin Point. These were not very productive, and only 3 distinct species were recognised.

The 2 species named were *Echiniscus spitsbergensis*, var. *spinuloides*, and *Macrobiotus echinogenitus*. The third was only known from an egg, which had hemispherical processes (Plate I. fig. 4). This egg is like one figured in "Scottish Alpine Tardigrada" (6), Plate III. fig. 10, but the Arctic egg is very much larger than the Scotch one. These eggs answer the description of "raspberry-form" given by DOYÈRE to the eggs of his *M. oberhäuseri*, but no sufficiently developed young has been seen in them.

BEAR ISLAND.

In the single collection taken here the only Tardigrade found was *Macrobiotus annulatus*, MURRAY. The single example seen had the typical skin, claws, and pharynx, but it was not carrying eggs. *M. ornatus*, RICHTERS, is the only other species which I find recorded for Bear Island.

NOTES ON THE SPECIES.

Genus ECHINISCUS.

E. arctomys, EHR. (2).—A widely distributed species, ranging from Franz Josef Land to Kerguelen.

E. mutabilis, MURRAY (4).—The spines on the inner claws were seen in all the examples recorded.

E. wendti, RICHTERS (11).—Examples from Franz Josef Land had the long head seta blunt and slightly expanded at the tip.

E. spitsbergensis, SCOURFIELD (15).—Somewhat variable in the length of the processes, especially of the second dorsal process (on the second paired plates). The most divergent variety is described below. In all the localities where the variety was found the type was also present.

Var. *spinuloides*, var. nov. (Plate II. figs. 8*a* to 8*c*) :—

Distinctive Characters.—There are little sublateral spines on four segments (II., III., IV., and VI.) as in *E. spinulosus*, DOY. (1), and *E. oihonnæ*, RICHTERS (11). The second dorsal process is an elongate curved spine with very broad flat base.

The pattern of the plates consists of large hexagonal marks, which do not appear to stand above the general surface, and enclose each an obscure round mark. There is a blunt palp on the fourth leg. Length, 284μ. Claws, 32μ. Eggs up to five in the cast skin.

Franz Josef Land and Novaya Zemlya. A very similar variety is frequent in Scotland, but the spinules have not been seen. These are, however, often difficult to detect.

Echiniscus borealis, n. sp. (Plate I. fig. 1):—

Specific Characters.—Large (310μ long) plates fourteen, three pairs; first and second median, each divided into two distinct plates; third median, single. Spines numerous: *lateral*, a curved spine on ventral side of head, short curved spines on shoulder plate and first and second pairs, a long seta on lumbar plate; *dorsal* processes, a broad-based spine on the first pair, a similar spine and a small tooth on the second pair, a short broad spine on the third pair; lateral margins of shoulder plate and the three pairs, bearing many small spines, of which those on the third pair are largest. A strong straight spine on outside of fourth leg. Lumbar plate trefoliate. Head seta very long (160μ); palp at base triangular, pointed. No barbs on any claws. Fringe of sharp spines. Plates pellucid, dotted; connecting skin also dotted. Larva two-clawed.

This very distinct species belongs to that section of the genus in which there is a third pair of plates, after the third median plate. Other species having this peculiarity are *E. mutabilis*, Murray, *E. conifer*, *E. arctomys*, *E. islandicus*, Richters, and an undescribed species at which Prof. Richters is now working. The only one of these which possesses processes on any plates other than the head plate is *E. islandicus*. The lateral processes are similar in the two species, but the dorsal processes are entirely different, as will be best seen by comparing the figures. *E. islandicus* has, moreover, the plates quite smooth, and possesses rods in the pharynx.

The two-clawed young of *E. borealis* measured 192μ, and all the processes of the adult were present. Skins containing three elliptical eggs were found, the eggs measuring 72μ by 48μ. Franz Josef Land.

The spines on the first and second pairs of plates occupy an unusual position, being near the median line of the body instead of at the angle as usual. The ventral head seta, the little lateral spines, and the straight seta beside the fringe on the last legs are all unusual processes possessed by no other species.

As only skins have been seen, it is unknown whether there are rods in the pharynx, as in *E. islandicus*.

Found only at one station, Cape Mary Harmsworth, Franz Josef Land.

E. muscicola (9).—This species must be regarded as insufficiently described, as it was not found mature, and several characters necessary to discriminate species are not mentioned. An animal found in Franz Josef Land comes nearest to *E. muscicola*, but the lateral setæ are *a*, *c*, *d*, *e*, instead of *a*, *b*, *c*, *d*. This example was also immature.

Genus Macrobiotus.

M. oberhäuseri, Doy.? (1).—No pigmented examples were found. An animal got in moss from Prince Charles Foreland agreed with this species in characters of pharynx and claws.

M. zetlandicus, MURRAY (8).—This species, recently discovered in Shetland, was abundant also in Spitsbergen. It is easily distinguished from all other known species by the short thick rods in the pharynx, each deeply two-lobed on the outer side.

M. annulatus, MURRAY (4).—Franz Josef Land, in two localities, and Bear Island. Animals typical, but none seen carrying the egg-sac in the manner so characteristic of the species.

M. augusti, MURRAY? (8). (Plate II. figs. 13*a*, 13*b*.)—Previously known only from Fort Augustus in Scotland. The identification is not quite certain, and depends on the three narrow rods in the pharynx, the smooth eggs, and the form of the claws. The middle rod is not decidedly shorter than the others, as in Scotch examples.

Another example, with equally narrow rods and similar claws, had only two rods, and thus resembles the newly hatched young, as found in Scotland.

M. ornatus, RICHTERS (10).—Found only at Red Bay, Spitsbergen, where it was abundant. Some skins with two eggs were found.

M. tuberculatus, PLATE (9).—Very insufficiently described by PLATE, whose figure and text are contradictory. It is likely that there are several tubercled species besides *M. sattleri* and *M. papillifer*, as I have found tubercled animals with different types of pharynx.

An example from Prince Charles Foreland agrees with PLATE's description in having very divergent claws. The tubercles are large and papillose; there are four on each chief segment and on each intermediate segment. The two pairs of claws are similar, and one claw of each pair is longer. The pharynx is shortly oval, with three short rods, increasing in size from first to third, besides a nut attached to the gullet. There are two dark eyes. In size it is larger than other tubercled examples seen, measuring 300μ in length.

M. tetradactylus, GREEFF? (3).—An animal found in Prince Charles Foreland is referred doubtfully to this species.

Macrobiotus, sp.—In Franz Josef Land were found some examples of a species which is common at the margins of Scottish lochs, and which is believed to be an undescribed species. The claws are of the *oberhäuseri* type, and the pharynx has two equal short rods, a nut attached to the gullet, and a "comma." In Scotland the cells forming the walls of the stomach are usually filled with blue granules. In specimens preserved in spirit it is impossible to tell if the blue granules have been present. The eggs are smooth, and are laid in the skin. See figure in "Tardigrada of the Scottish Lochs" (4), Plate III. fig. 12, where it is erroneously named *M. islandicus*. At that time the eggs had not been observed, or the error would have been avoided. An example also occurred in Prince Charles Foreland.

Macrobiotus, sp.—In Franz Josef Land there were found several examples of a *Macrobiotus* which lays elliptical eggs in the cast skin. The eggs had been attacked by a parasite, possibly a kind of *Saprolegnia*. From each egg there proceeded a tube which penetrated the back of the skin of the parent and formed a slight expansion just

outside it (Plate II. fig. 9*a*). The eggs and tubes were empty, but in Scotland the living parasite has been seen infesting the body of the Tardigrade.

The species attacked appear to be undescribed. The pharynx (fig. 9*c*) has three rods, of which the middle one is shorter. This is a rare arrangement, only known in *M. augusti*, which has much more slender rods and differs in other respects. Carpenter's Rock, Franz Josef Land.

M. hufelandii, C. Sch. (14).—A cosmopolitan species. The egg is supposed to vary considerably, but I expect the most aberrant varieties to prove permanent races, if not species. There is a circlet of radiating lines round the base of each process. One form in Franz Josef Land lacked this circlet. According to Richters, the egg producing the simplex form has the processes closer set.

M. intermedius, Plate (9).—Only found in Franz Josef Land. No eggs were seen, but Richters has observed them in Spitsbergen, and they are occasionally found in Scotland.

M. echinogenitus, Richters (11).—Probably as widely distributed as *M. hufelandii*. The eggs vary greatly. The spines are usually acuminate, and are close together at the bases. They may be short or long, and may be widely separated at the bases. Some other species have very similar eggs, so that it is unsafe to identify from the egg alone, unless it contains a well-developed young.

Var. *areolatus*, var. nov. (Plate II. figs. 14*a* to 14*d*):—

Distinctive Characters.—Of large size, up to 800μ. Eggs very large, up to 180μ over spines, or 95μ without spines; spines papillose, separated at the bases, the intermediate surface of the shell marked with irregular polygonal spaces, symmetrically arranged. The claws are united for a short distance at the base. The pharynx has three narrow rods, nearly equal, and no comma. Claws of largest examples 40μ long; fat-cells up to 15μ long.

Spitsbergen and Franz Josef Land; also known from mountain tops in Shetland, and the mainland of Scotland, the Himalaya, etc.

After the characters of the egg, the most striking difference is the absence of comma in the pharynx. Many young have been seen to issue from eggs. The teeth are not acicular, but broad and lance-shaped at the ends. Each long claw has two supplementary points.

M. dispar, Murray (7).—It is only recently that this species has been distinguished from *M. macronyx*. The rare spiny egg has been seen within a cast skin from Prince Charles Foreland. The dorsal conical processes, which have nowhere been found so largely developed as in Loch Tay in Scotland, were fairly large in a skin found among moss growing on an ancient walrus skull at an elevation of over 400 feet in Franz Josef Land.

M. ambiguus, Murray (8).—Another species closely resembling *M. macronyx*, and only recently recognised as distinct. Though very similar to *M. dispar*, it has a very different egg, much larger (diameter over spines 132μ), with larger spines, like those of some forms of *M. echinogenitus*, touching at the bases.

In Prince Charles Foreland adults reached to 800μ long.

M. crenulatus, RICHTERS (12). (Plate I. figs. 6*a* to 6*c*.)—Discovered by RICHTERS in Spitsbergen, this species was observed in Prince Charles Foreland and Franz Josef Land. In our examples the last leg was sometimes papillose, as in RICHTERS' *M. granulatus*, and there was a papillose process on the front of each leg, not referred to by RICHTERS. The crescent in front of the claws is merely wrinkled, not spiny, and the rods in the pharynx are not nearly so thick and strong as in examples of *M. granulatus* which Prof. RICHTERS has kindly sent me.

The colour was dark brown. The largest examples measured 750μ long, the pharynx 66μ long.

M. harmsworthi, sp. n. (Plate I. figs. 7*a* to 7*d*) :—

Specific Characters.—Size moderate, blood pale yellow. Teeth nearly straight, with bearers; pharynx somewhat long, oval; thickenings, four in each row; first, short, attached to the gullet, second, third, and fourth narrow rods, the fourth a little longer than the others. Claws of *hufelandi* type, united half way, one claw of each pair much longer, with two large supplementary points. A crescent-shaped ridge in front of each pair of claws, crenate on the last legs, plain on the others. Eyes very small.

Length up to 500μ, pharynx 52μ, claws 24μ.

Related to *M. crenulatus*, RICHTERS, it is distinguished by the pharynx with three narrow rods, and the crescent crenate instead of closely wrinkled.

Cape Mary Harmsworth, Franz Josef Land, Spitsbergen. Also in Shetland.

M. arcticus, sp. n. (Plate I. figs. 5*a* to 5*f*) :—

Specific Characters.—Spiny eggs with rod-like blunt processes embedded in hyaline matrix. Egg small, oval or round; spines subclavate, slightly expanded, and blunt at tips. Pharynx short, oval; thickenings three in each row; first, nut, attached to gullet; second and third short rods, almost as broad as long; teeth curved, with bearers. Claws V-shaped, one of each pair longer, the long claw of one pair very long. Dark eyes.

The adult is unknown, but the young of *Macrobiotus* rarely differ in any important respect from the adult. Diameter of egg, over the spines, 83μ, pharynx in egg 20μ.

The only close relative is *M. hastatus*, MURRAY, which has egg spines similarly embedded in a hyaline matrix. The egg of that species is larger, the spines larger and more complex, the rods in the pharynx longer.

Prince Charles Foreland and Franz Josef Land (fig. 5*f*).

The egg from Franz Josef Land is smaller, oval, 65μ in long diameter. A similar egg to the smaller one, but with thicker spines, has been found in South Africa.

Another egg of the same type, but with shorter, round rods, occurred in Loch Ness, and is figured in "Scottish Tardigrada" (8), Plate IV. figs. 27*a* to 27*d*. The animal hatched from this last egg was very similar to *M. arcticus*.

M. pullari, MURRAY (8).—An egg found in Prince Charles Foreland resembles that of this species and *M. dispar*. In size it comes nearest to *M. pullari*.

M. islandicus, RICHTERS.—Though not definitely known to exist in Spitsbergen, some eggs found in Prince Charles Foreland and Recherche Bay (Plate I. figs. 2 and 3), though not exactly like RICHTERS' figure ("Isländische Tardigraden," p. 376), may belong to this species.

Macrobiotus, sp. (Plate I. fig. 4.)—A large egg, with hemispherical processes, also occurring in Novaya Zemlya and on Ben Lawers in Scotland. The species producing it is not yet known.

Genus DIPHASCON.

D. chilenense, PLATE (9).—Prince Charles Foreland. Previously known as an Arctic species only from Tromsö.

D. alpinum, MURRAY (6).—Prince Charles Foreland. Now known as Arctic, Antarctic, and from one mountain top in Scotland (6).

D. spitsbergense, RICHTERS (11). (Plate II. fig. 12.)—Prince Charles Foreland. Spitsbergen; Carpenter's Rock, Franz Josef Land.

D. scoticum, MURRAY (5).—Prince Charles Foreland and Recherche Bay, Spitsbergen; Cape Gertrude, Franz Josef Land. Of smaller size than *D. spitsbergense*, and easily known by the much more slender gullet. Only, as yet, known in northern lands. Three eggs in skin.

D. angustatum, MURRAY (4).—By the two narrow rods in the pharynx, the animal figured (Plate II. fig. 11) comes nearest this species, but has the rods narrower and the first relatively longer. It attained a length of 380μ. The encysted animal was seen.

Diphascon, sp. (Plate II. fig. 10.)—This insufficiently observed species has the rods in the pharynx as in *D. angustatum*, but is undoubtedly distinct, as the pharynx is relatively shorter and broader, and the gullet is very slender.

Diphascon, sp.—Also insufficiently studied, but distinct from all known species. There are four short rods in the pharynx, besides a nut and a comma. In this respect it resembles, among known species, only *D. chilenense*, but it has a thick gullet, relatively short. The claws are of the usual *Diphascon* type.

SUMMARY.

Including the species found in Mr BRUCE's collections, there are 40 species of Arctic Tardigrada on record. There are in addition 4 undescribed species which require further study, making a total of 44 species. Five of these species are as yet unknown, except in the Arctic Regions.

There are 32 of the Arctic species also found in Scotland, 17 in Central Europe, 9 in Asia, 5 in Africa, 6 in America, while 8 extend into the Antarctic Region.

Several of the records are of doubtful value—some of them refer to insufficiently described species, for ever unrecognisable—yet the majority are good species, and

there are undoubtedly many more to be discovered, as various eggs are known which cannot be referred to any of the described species.

In this paper the Arctic Region is restricted to the area within the Arctic Circle, following RICHTERS' practice in "Arktische Tardigraden," so that our results may be easily comparable. Climatically, Iceland, S. Greenland, and parts of Northern Europe outside the Arctic Circle should, no doubt, be treated along with the region within the Arctic Circle.

The term Antarctic Region in the following table has a laxer meaning, and includes all the lands south of the great continents for which any records are available. This treatment was necessitated by the different climate of the southern Polar Region, within which, defined as bounded by the Polar Circle, only one Tardigrade is known.

In the appended table of all the Arctic species known, the aim is to give a general view of the distribution of each species in Arctic lands and over the world. These records of distribution do not profess to be nearly complete, as I have failed to have access to several works containing records.

For the world distribution I am mainly indebted to the table in RICHTERS' "Arktische Tardigraden," but in order to give as comprehensive a view as I could, I have added many notes of Asian, African, and American species not yet published.

In the table the records are given under eleven headings, five of which give the principal Arctic lands for which we have records—the others being Scotland, Central Europe, Asia, Africa, America, and the Antarctic Region.

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(14) SCHULTZE, C. A. S., "Macrobiotus hufelandii," Oken's *Isis*, 1834, p. 708.
(15) SCOURFIELD, D. J., "Non-Marine Fauna of Spitsbergen," *Proc. Zool. Soc. London*, 1897.

Complete List of Arctic Species (with General Distribution).

	Arctic					Scotland.	Central Europe.	Asia.	Africa.	America.	Antarctic Region.
	Spitsbergen.	Franz Josef Land.	Novaya Zemlya.	Bear Island.	North Europe.						
Echiniscus arctomys, Ehr.	×	×			×	×	×	×	×		×
E. mutabilis, Murray	×	×				×		×			
E. wendti, Richters	×	×			×	×					
E. spitsbergensis, Scourfield	×	×	×		×	×					
E. borealis, sp. n.		×									
E. muscicola, Plate		×				×	×				
E. testudo, Doy.	×						×				
E. blumi, Richters	×					×	×				
E. oihonnæ, Richters	×				×	×	×				
E. merokensis, Richters					×						
E. victor, Ehr.					×		×				
E. spinulosus, Doy.	?						×				
E. spiculifer, Schaudinn	?										
Milnesium tardigradum, Doy.	×					×	×	×	×	×	
Macrobiotus oberhäuseri, Doy.	×				×	×	×	×			×
M. zetlandicus, Murray	×					×					
M. tetradactylus, Greeff	×				×	×	×			×	×
M. ornatus, Richters	×			×	×	×	×				
M. tuberculatus, Plate	×					×	×				
M. annulatus, Murray		×		×		×					
M. augusti, Murray		×				×					
M. macronyx, Duj.	×					×	×			×	
M. hufelandii, C. Sch.	×	×			×	×	×	×	×	×	×
M. intermedius, Plate	×	×			×	×	×	×		×	×
M. echinogenitus, Richters	×	×	×		×	×	×	×	×		×
M. dispar, Murray	×	×				×		×			
M. ambiguus, Murray	×	×				×					
M. pullari, Murray	×					×					
M. coronifer, Richters	×				×	×					
M. crenulatus, Richters	×	×				×					
M. granulatus, Richters					×						
M. harmsworthi, sp. n.	×	×				×					
M. arcticus, sp. n.	×	×				×			×		
M. islandicus, Richters	×					×					
M. dujardini, Doy.	×										
Diphascon chilenense, Plate	×				×	×	×	×		×	×
D. alpinum, Murray	×					×					×
D. spitsbergense, Richters	×	×				×					
D. scoticum, Murray	×	×				×					
D. angustatum, Murray	×	×				×					
	33	19	2	2	15	32	17	9	5	6	8

EXPLANATION OF PLATES.

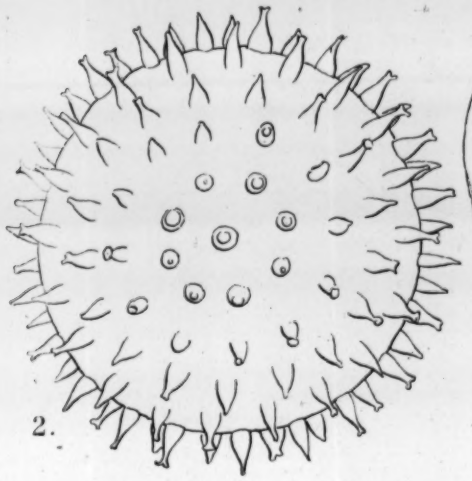
Plate I.

1. *Echiniscus borealis*, sp. n.
2. *Macrobiotus islandicus*, Richters? egg.
3. *Macrobiotus islandicus*, „ „
4. *M.*, sp.? egg.
5*a*. *M. arcticus*, sp. n., teeth and pharynx.
5*b*. „ egg.
5*c*. „ some rods of the egg.
5*d*. „ claws.
5*e*. „ one pair claws, side view.
5*f*. *M. articus*, smaller oval egg.
6*a*. *M. crenulatus*, Richters, teeth and pharynx.
6*b*. „ side view of leg and claws.
6*c*. „ claws and wrinkled crescent.
7*a*. *M. harmsworthi*, sp. n., egg.
7*b*. „ teeth and pharynx.
7*c*. „ claws and crenate crescent.
7*d*. „ side view of claws.

Plate II.

8*a*. *Echiniscus spitsbergensis*, Scourfield, var. *spinuloides*, var. nov.
8*b*. „ „ outer and inner claws.
8*c*. „ „ portion of surface marking.
9*a*. *Macrobiotus*, with eggs attacked by parasite.
9*b*. „ pharynx.
10. *Diphascon*, sp., pharynx.
11. *D. angustatum*, Murray, pharynx.
12. *D. spitsbergense*, Richters? pharynx.
13*a*. *M. augusti*, Murray, gullet and pharynx.
13*b*. „ claws.
14*a*. *M. echinogenitus*, Richters, var. *areolatus*, var. nov., egg.
14*b*. „ pharynx in egg.
14*c*. „ furca of tooth.
14*d*. „ claws.

MURRAY: ARCTIC TARDIGRADA.—PLATE I.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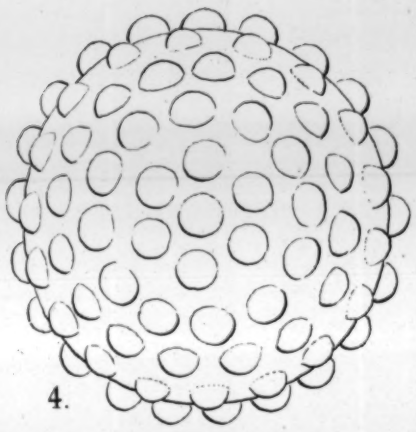
3.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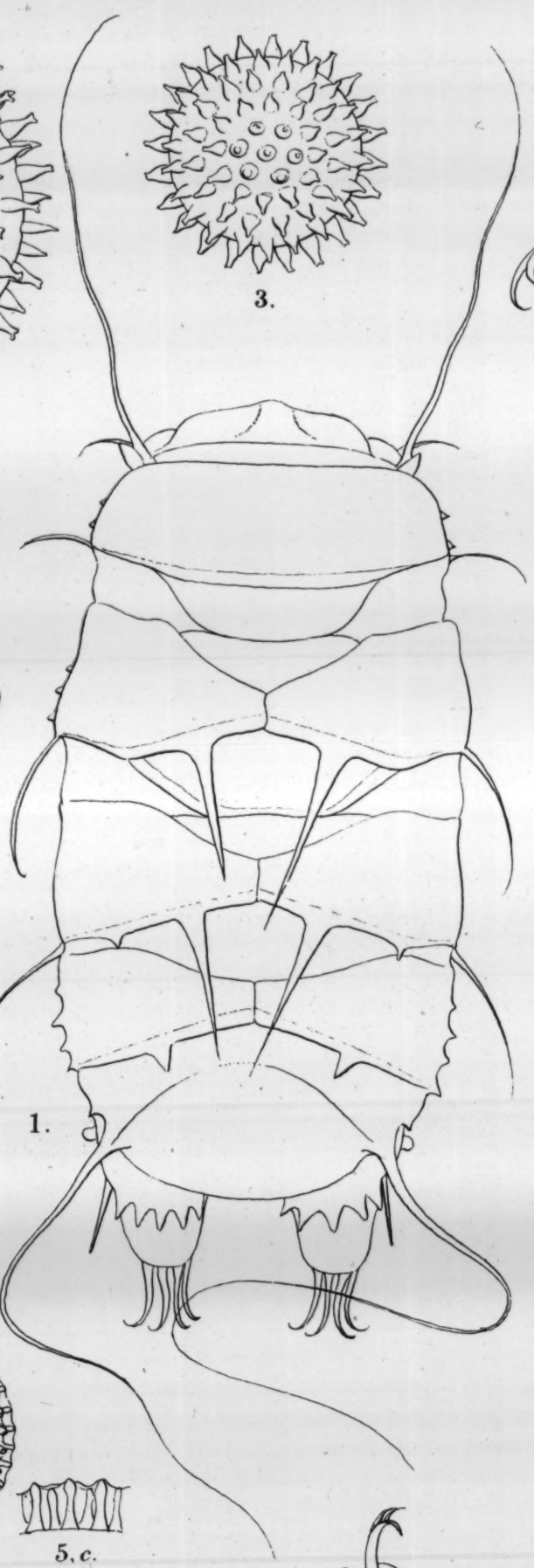
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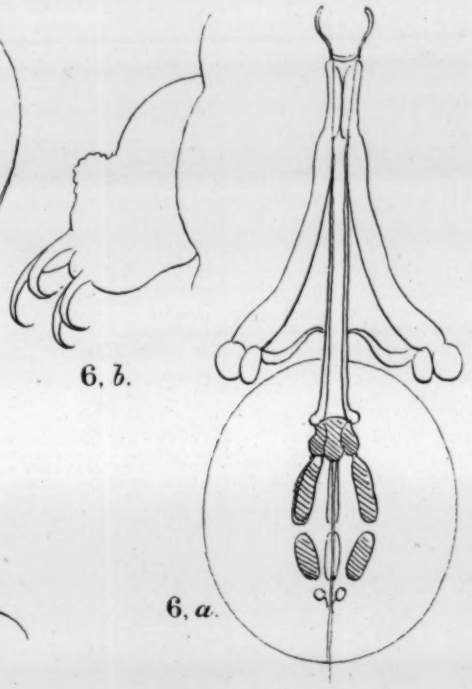
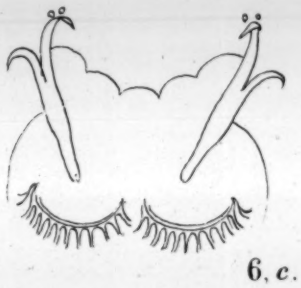
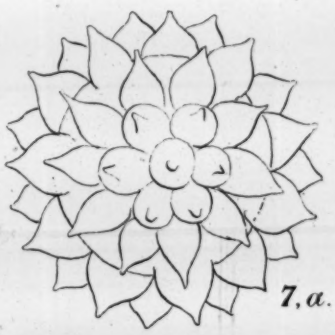
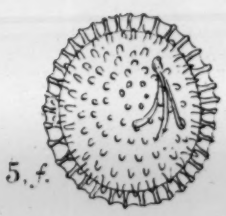
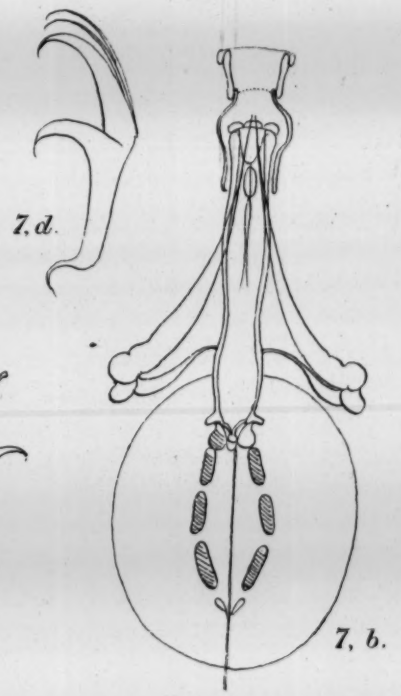

6, *b*.

6, *a*.

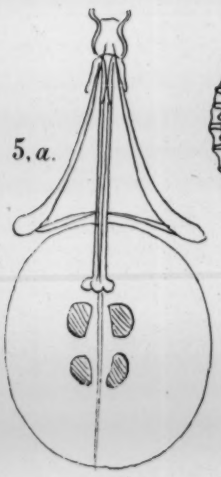

6, *c*.

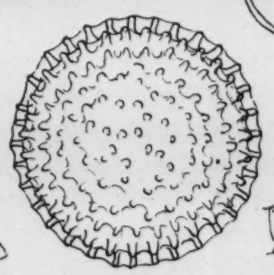

7, *a*.


5, *f*.


7, *d*.

7, *b*.


5, *a*.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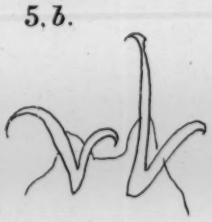
5, *c*.


5, *d*.

5, *e*.

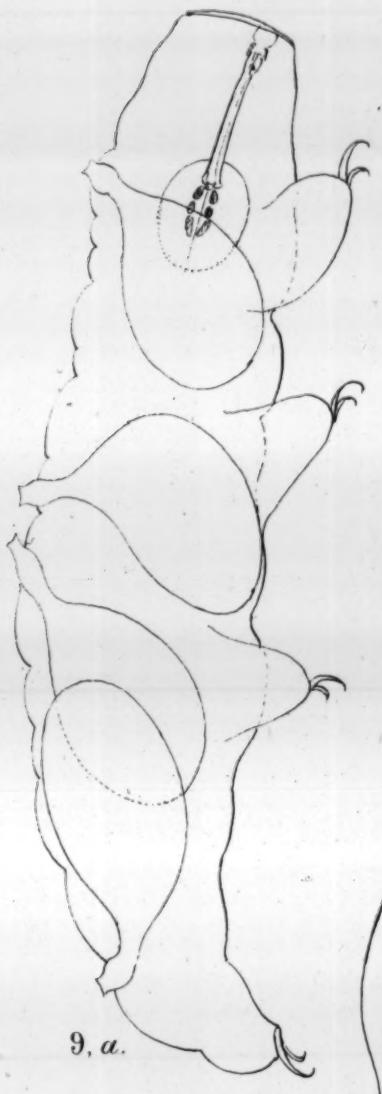
7, *c*.

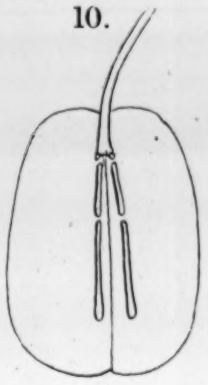
J. Murray, del. ad. nat.

McFarlane & Erskine, Lith. Edin.r

1, ECHINISCUS BOREALIS, sp. n. 5, MACROBIOTUS ARCTICUS, sp. n. 6, M. CRENULATUS, Richters.
7, M. HARMSWORTHI, sp. n. 2, 3, 4, EGGS OF MACROBIOTUS, species unknown.

MURRAY: ARCTIC TARDIGRADA.— PLATE II.


9, a.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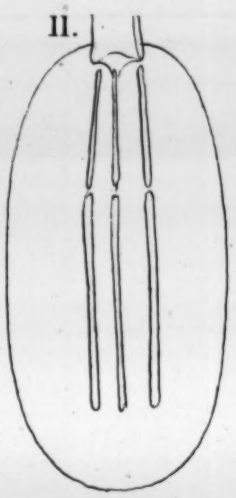
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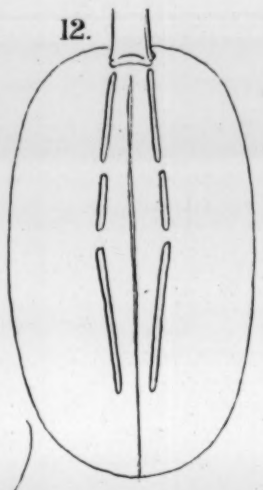
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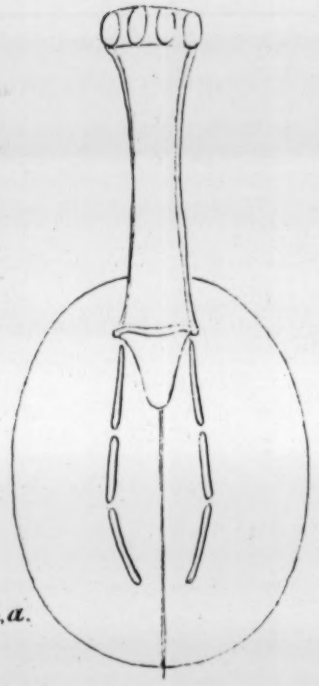
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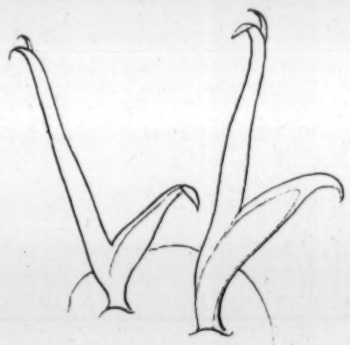
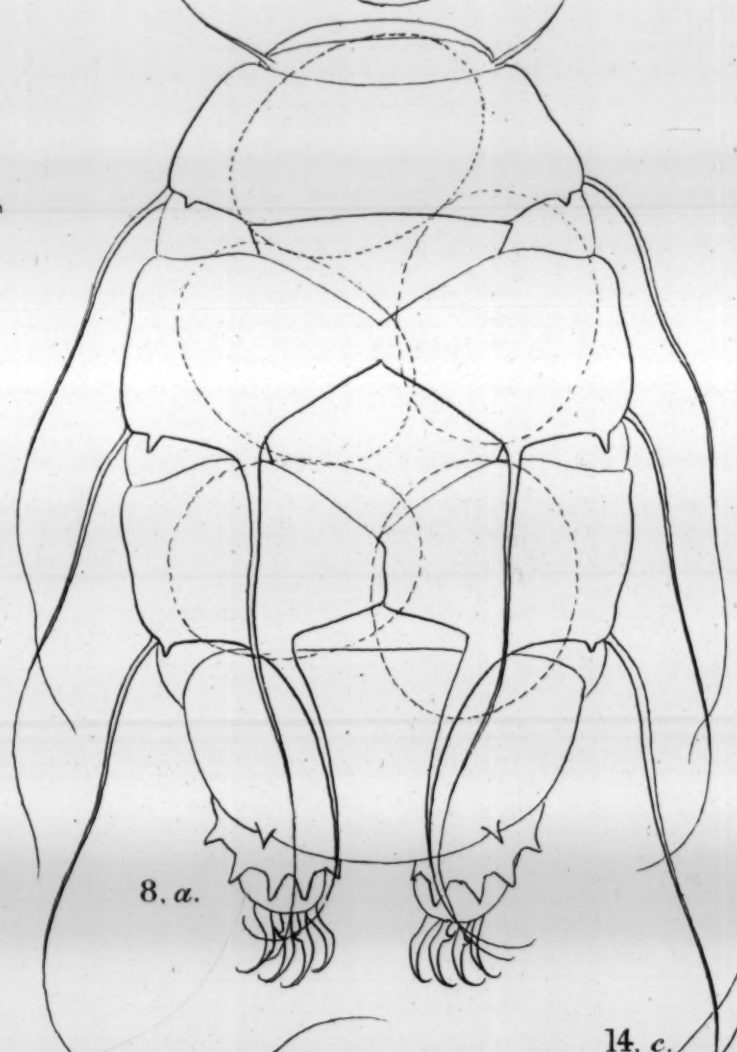
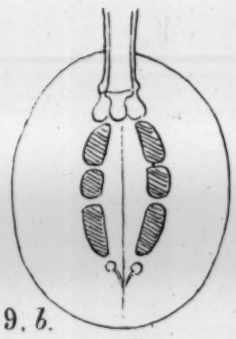

13, b.


8, a.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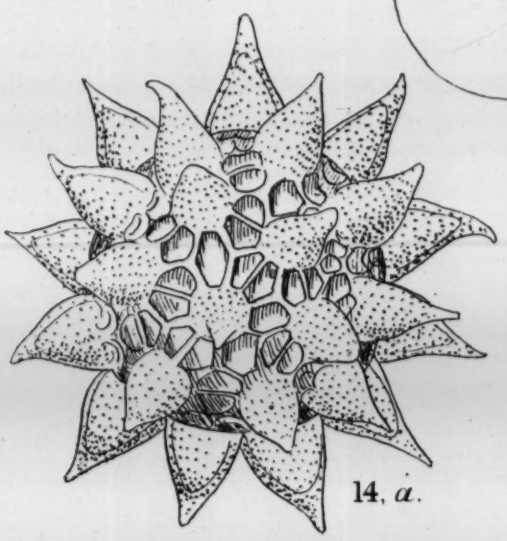
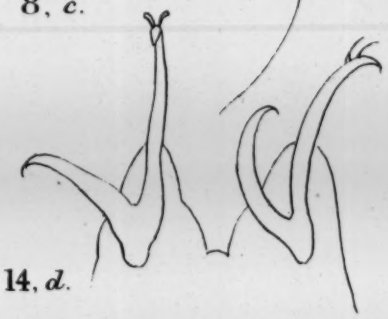
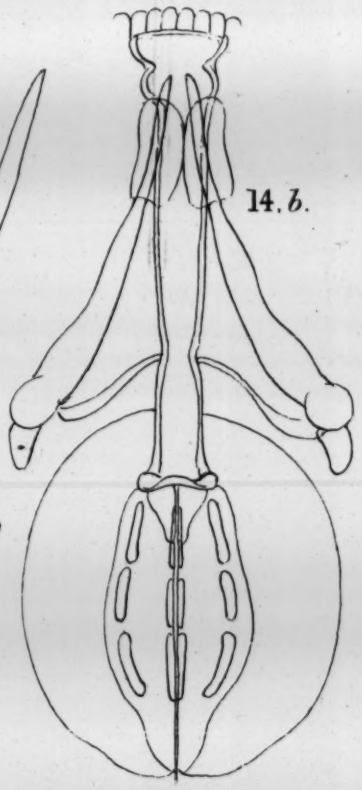

14, a.

8, b.

8, c.

14, c.


14, d.


14, b.

J. Murray, del. ad. nat.

McFarlane & Erskine, Lith. Edin.r

8. ECHINISCUS SPITSBERGENSIS Scourfield, variety SPINULOIDES, var. nov. 9. MACROBIOTUS, with parasite.
10. DIPHASCON, sp. 11. D. ANGUSTATUM. Murray. 12. D. SPITSBERGENSE, Richters ?
13. M. AUGUSTI, Murray? 14. M. ECHINOGENITUS, Richters. variety AREOLATUS.

XXVI.—A Monograph on the general Morphology of the Myxinoid Fishes, based on a study of Myxine. Part II. The Anatomy of the Muscles.

By **Frank J. Cole**, B.Sc. Oxon., Lecturer in Zoology, University College, Reading. *Communicated by* Dr R. H. Traquair, F.R.S. (With Four Plates.)

(Read July 16, 1906. Issued separately June 20, 1907.)

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1. Introduction.

The first part of this work was published in the *Transactions* of the Society for 1905, when the present section was promised by the end of the same year. But the labour of revising the whole work on the sections and of posting all the muscles in the extensive series of key sections along with the skeleton has been much greater than was anticipated, and hence the delay. This labour, however, is amply repaid by the knowledge that one is now in a unique position for studying the blood-vessels and nerves; for not only has every fraction of the skeleton and muscles been microscopically explored, but the information obtained is immediately and completely available on reference to the key sections. When the whole work is completed and all the systems have been entered in these sections, I hope to obtain a grant to enable me to publish them as an atlas. As far as I am aware, no animal has been studied throughout in this way before.

The terminology adopted in the present part (with a few slight alterations) is that of P. Fürbringer (7). I have made no attempt to revise it, for the same reason that

induced me to accept the existing nomenclature of the skeleton, *i.e.* that no revision without the evidence of the vessels and nerves could have any permanent value. It is clear, however, that a revision is necessary; and, for example, the transversus oris may possibly have to be broken up into three discrete muscles.

I am much indebted to the friendly interest of Baron A. KLINCKOWSTRÖM, who has been kind enough to present me with a number of excellent unpublished drawings of *Myxine*. Due acknowledgment will be made when these are put to any use. I also wish to express my indebtedness to the Government Grant Committee of the Royal Society for a grant which has defrayed the expenses of this research.

Perhaps I may repeat the statement made in my first Part, that although the present work is purely anatomical, the morphology of the animal will be exhaustively considered when the whole facts are available and have been co-ordinated. In conclusion, I feel it is only right to refer here to the great assistance in preparing the key sections given by EDINGER's projection apparatus, as made by Leitz. Combined with a Zeiss A lens the sections may be easily and quickly drawn with great accuracy. One may hope that this apparatus will be sufficiently improved in the future to be available with higher powers.

2. HISTOLOGY OF THE MUSCLES. (Fig. 7, *a–e*, numerals *1–5*.)

I do not propose in this section to enter into the histology of the muscles proper, but simply to consider such microscopical details as have an anatomical bearing. A transverse section of the parietal muscles reveals the fact, as recognised by MAURER, that the muscle fibres are (at least) of two kinds, which are easily distinguishable even with the low power of the microscope. There are other types of muscle fibre present in *Myxine*, especially, as we should expect, in the tail, but these do not concern us here. The two types mentioned above are the small plasmic "red" fibres, which physiologists have shown to occur in rapid or strenuous muscles, and the large aplasmic "white"* fibres which are found in sluggish or tonus muscles. Of the two, the red fibres are much less numerous, but on account of their very rich vascular supply they are strikingly picked out if the section has been stained with Mann's methyl-blue-eosin. The red fibres are either absent or very sparsely scattered at the anterior end of the parietalis, and also throughout the greater part of the caudal region, and elsewhere in the thin ventral portion of the muscle. Apart from this, they may be said to characterise the parietalis generally.

The M. parietalis is formed by a number of dorso-ventrally compressed fasciculi, which in transverse section appear as flattened sausage-shaped masses, arranged (more or less) at right angles to the median vertical axis of the body. The greater part of

* I use the terms "red" and "white" on account of their convenience, but I have not examined living material to ascertain whether these fibres, as is often the case, actually are red and white in colour. Their rich vascularity at least should give the plasmic fibres a reddish tinge in *Myxine*. Well-known examples of the two kinds of fibres are the predominantly red fibres of the pectoral muscles of the pigeon and the white fibres of the similar muscles of the fowl.

the external surface, *i.e.* the surface abutting on the subcutaneous blood sinus, consists of red fibres two or three rows deep (apparently observed by SCHNEIDER), and from this crust there penetrate inwards, often right through the thickness of the muscle, numerous horizontal sheets of red fibres, each of which is shown in transverse section to be formed of a *single* row of fibres placed end to end, like a row of bricks. It is curious that, as already pointed out by MAURER, the red fibres are confined to the *ventral* surface of the fasciculi, the remainder of each fasciculus (with its dorsal surface) being formed entirely of the white fibres. Thus every fasciculus has a ventral sheath of red fibres. In the Lamprey, according to MAURER, the red fibres extend right round the fasciculi. The following descriptions are based on fibres selected from the same specimen, and take no account of the state of contraction in which they happened to be.

M. parietalis.

White Fibres (fig. 7, *a*).—These are of large size and are formed of small sarcostyles, (*1*),* which are very numerous and closely packed. The transverse striation is sharply marked, and there is no peripheral zone of sarcoplasm nor a peripheral blood plexus. The nuclei (*2*) are numerous, narrow, very elongated, and *mostly internal*, although some are situated superficially (all seen in transverse section in the figure). According to MAURER, the distorted appearance which these nuclei often present is due to the pressure of the surrounding sarcostyles. They are also said to resemble the sarcolemma nuclei.

Red Fibres (fig. 7, *b*).—These are of much smaller size and have slightly larger sarcostyles (*1*) which are not so concentrated (*i.e.* not so numerous). According to MAURER, the sarcostyles are here aggregations of smaller fibrillæ, but I find no evidence of this. Sarcoplasm (with an occasional stray nucleus —*2*) is quite visible as a packing between the sarcostyles. According to MAURER, however, there are no internal nuclei in the red fibres; and whilst this is not literally true, it is correct to say that internal nuclei are typically absent in the red fibres. The transverse striation is not so well marked as in the white fibres, but the longitudinal striation is very apparent. Peripherally there is a zone of sarcoplasm (*3*) which lodges the large oval or circular true nuclei (*4*) of the fibre. The nuclei are here, therefore, not central, as in the white fibre, but peripheral. Round each fibre there is a rich peripheral blood plexus (*5*) which is very striking in longitudinal sections stained with methyl-blue-eosin. It is obvious that these are rapid fibres undergoing considerable tissue change, and hence the zone of nutritive sarcoplasm with its extensive vascular supply.

M. cordis caudalis. (Fig. 7, *c*.)

This muscle consists of red fibres only. These on an average are much smaller than the similar fibres of the parietalis, but they vary considerably in size. The figure has

* Perhaps these should be regarded rather as *fibrils* which have not collected together to form clearly defined muscle columns or sarcostyles.

been drawn from one of the medium-sized fibres, the largest being about the size of the red fibre figured from the parietalis. The sarcostyles (*1*) are generally quite small and closely packed, but may be of variable size. There is no appreciable internal sarcoplasm, and I have only very rarely seen internal nuclei. Most of the fibres have uniformly small sarcostyles, and the transverse striation is somewhat indistinct. The peripheral sarcoplasm (*3*) is relatively more abundant than in the parietalis red fibre, and contains strings of large oval or round nuclei (*4*). Although the muscle is very vascular (*5*), the capillaries are not arranged in a definite rich plexus round each fibre as in the parietalis red fibre—perhaps not necessary, owing to their smaller size.

M. velo-quadratus. (Fig. 7, *d.*)

Also consists of red fibres only. They are of practically uniform size, much smaller than the red fibres of the parietalis, and about equal to the medium fibres of the cordis caudalis. The sarcostyles (*1*) are exceedingly small, of uniform size, and fairly closely packed, and there is no appreciable internal sarcoplasm. The transverse striation generally is faint, and there is an extensive peripheral zone of sarcoplasm (*3*) with large unusually round nuclei (*4*). I have seen a large nucleus in the centre of the sarcostyles, but it may be said that the nuclei are typically peripheral. The muscle is very vascular (*5*), more so than the cordis caudalis, but not to such an extent as the red fibres of the parietalis. There is no plexus round each fibre as in the latter muscle, but large capillaries penetrate very freely between the fibres.

M. velo-spinalis. (Fig. 7, *e.*)

The histology of this muscle agrees with that of the velo-quadratus, but the following points may be noted. The fibres are smaller, and there is occasionally a patch of sarcoplasm in the centre of the fibre in which I have (rarely) found a central nucleus, but neither of these features is at all characteristic of the muscle. The striation is very faint and the muscle is highly vascular (*5*).

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3. *M. tentacularis posterior.* (Figs. 8, 9, 10, *t. p.*)

J. Müller, *Zurückzieher der Tentakeln* (p. 258).

Arises just behind and over the eye in the apex of the angle formed by the two limbs of the second myotome, or in some cases by the upper limb of the second myotome and the backward extension of the first (cp. fig. 9). The origin is from the strong membrane constituting the fascia superficialis externa of J. Müller. The M. nasalis arises largely from the same membrane. The eye lies between this muscle and the palatine bar. The muscle passes forwards, most of it at the side of the lateral wall of the brain case. Opposite the posterior end of the nasal capsule it begins to

flatten out so as to become ribbon-shaped, and is opposed internally to the M. palato-ethmoidalis superficialis, lying at the side of the nasal capsule. In front of the capsule it courses superficially as a very broad ribbon-shaped muscle at the side of the head. Anteriorly, it separates off below a small bundle which is inserted externally into the sheath of the base of the third tentacle. The larger dorsal part then rapidly narrows down, and is inserted externally into the basal sheath of the first tentacle. It is obvious that this muscle is something more than the retractor of the first and third tentacles, and in fact most of its fibres, constituting the middle portion of P. FÜRBRINGER, pass straight forwards and terminate on the tough spongy tissue of the snout between, and in the region of, the first and third tentacles.

J. MÜLLER states that in *Bdellostoma* this muscle arises from the palatine bar and is inserted into the first, second, and third tentacles *only*, *i.e.* there is no middle portion. In *Myxine* it is everywhere widely separated from the palatine bar, and is, further, not inserted into the second tentacle. Any movement of the first tentacle, however, would necessarily affect the second. P. FÜRBRINGER also queries MÜLLER'S statement of the origin from the palatine bar mentioned above. The morphology of this interesting muscle I leave over until its innervation is described.

4. *M. tentaculo-ethmoidalis.* (Figs. 3, 10, 11, *t. e.*)

J. MÜLLER (in part), *Compressor des Mundes, Mundschliesser* (p. 259).

A clearly defined muscle, coursing obliquely backwards and outwards, and compressed from side to side into a vertical band, the dorsal border appearing behind on the lateral surface above the transversus oris, and the ventral border appearing on the ventral surface between the transversus oris and the copulo-ethmoidalis, but the two latter muscles approximate posteriorly, and there exclude the posterior end of the tentaculo-ethmoidalis from the ventral surface. It thus extends for a great part of its course from the dorso-lateral surface of the snout on to the ventral surface of the same, but is separated from the skin at both extremities by the elaborate blood sinuses which exist at this region, and, further, it is partly covered dorsally by the upper limb of the tentacularis posterior.

The tentaculo-ethmoidalis arises mostly from the entire lateral surface of the zone of soft cartilage forming the anterior end of the subnasal bar, but the origin was continued also on to the same surface of the hard cartilage part. It is, however, soon displaced from the latter by the copulo-ethmoidalis, when it takes up a position in the extensive concavity on the external surface of the latter muscle. In the sections, and especially on the right side, some fibres arise in front of the origin given above from the ventro-external surface of the transverse labial cartilage. There is also in the sections some confusion between the origin of the present muscle and the ethmoideo-nasalis, but I could not establish with certainty any real mingling of the fibres of the two muscles.

The tentaculo-ethmoidalis lies internal and somewhat dorsal to the transversus oris, and in fact in dissection (except in Perenyi material) there is some difficulty in satisfactorily separating them, as mentioned by P. FÜRBRINGER. J. MÜLLER evidently had this experience also, for he fails to distinguish between the two muscles, and describes them together under the name given above. The sections, however, demonstrate conclusively their complete independence.

From its origin the muscle courses backwards and outwards, wedged in between the copulo-ethmoidalis and the transversus oris, its fibres diverging ventro-dorsally like a fan, to terminate, after a short course, on the external lateral fascia between the two muscles just mentioned above in front of the base of the third tentacle and in front of the posterior vertical portion of the lateral labial cartilage. P. FÜRBRINGER asserts that it is inserted into the base of the third tentacle, but I find no evidence of this in dissections, and it is certainly not the case in the sections.

5. *M. transversus oris.* (Figs. 3, 10, 11, *t. o.*)

J. MÜLLER (in part), *Compressor des Mundes, Mundschliesser* (p. 259).

A complex and diffuse muscle. as defined by J. MÜLLER and P. FÜRBRINGER, and said by ALLIS to consist in *Bdellostoma* of "two transverse subnasal muscles." In dissections a division of the muscle into two parts seems to be indicated in *Myxine* also, although not mentioned by P. FÜRBRINGER, but a complete separation is not possible, and the sections show that the division is not a real one. Perhaps the two transverse muscles mentioned by ALLIS are the two commissures described below from the sections (cp. fig. 10), in which case he does not include the greater part of the transversus oris of other authors.

I find some difficulty in reconciling my descriptions of this muscle based on dissections and on the sections. This may be, and perhaps is, due to the fact that it is difficult in dissections, however careful, to correctly define a small and irregular muscle closely packed up with and attached to other tissues in a confined space. On the other hand, the sections fail to convey a clear impression of the *ensemble* of the muscle, and then, again, the muscle may vary considerably. I have therefore thought it advisable to give two descriptions, one of a careful dissection of a $34\frac{1}{2}$ cm. Hag, and the other based on my large series of sections.

It will be convenient in the description of the dissection to divide the muscle into two regions, although, as stated above, this division is not sanctioned by the sections.

Posterior Region.—Lies, in a lateral view, apparently immediately in front of the tentaculo-ethmoidalis, to which it is somewhat closely attached, and seems to be quite distinct from the anterior region. This, however, is really due to the fact that many of the fibres, and especially the dorsal ones, are less transverse than those of the latter region. In the present specimen (see fig. 3) the most dorso-superficial fibres of the

posterior region were inserted into the first ring of the nasal tube in front of the ethmoideo-nasalis, and from thence passed obliquely backwards, outwards, and downwards under that muscle, as shown in the figure. I have not, however, seen this since. Some of the fibres arise (? insertion) from the so-called transverse labial cartilage (see Part I. p. 770) and also from the anterior extremity of the subnasal bar immediately below and in front of the origin of the tentaculo-ethmoidalis, but most of them arise from the stout ventro-lateral superficial fascia near the anterior extremity of the snout, course more or less transversely on to the adjacent dorso-lateral surface of the same side (cp. fig. 10), and are inserted (? origin) in front of the middle third of the *internal* portion of the third tentacular cartilage into the antero-internal fascia of the anterior portion of the head of the copulo-tentaculo-coronarius from the third tentacle.

Anterior Region.—More definitely transverse than the posterior region, and situated, in a lateral view, apparently anterior to it, and between it and the anterior division of the copulo-tentaculo-coronarius. Most of its fibres course direct from the tough ventro-lateral to the dorso-lateral fascia of the same side, and this region is reinforced by fibres from the first tentacle. Ventrally there is a distinct transverse commissure in front of and ventral to the anterior extremity of the subnasal bar, and seen after removal of the skin, the fibres of which arise partly from the bases of the second tentacles and partly from the antero-ventral fascia of the anterior region of the present muscle (= ventral commissure below—cp. fig. 10). All the fibres from the second tentacle, however, do not pass over into the commissure, but some of them pass on to the transverse labial cartilage and the anterior extremity of the subnasal bar (= dorsal pseudo-commissure below).

In the sections, the transversus oris arises (? insertion) by a pointed posterior extremity from the internal surface of the sheath of the third tentacular cartilage just within the contour of the body, and between the anterior division of the copulo-tentaculo-coronarius (below) and the posterior division of the same (above). The latter, however, soon dies away; and as it does so, the transversus oris is attached to its internal fascia and a number of fibres arise from this. The muscle has thus a double origin. It now courses forwards as a clearly defined muscle lying immediately above the anterior division of the copulo-tentaculo-coronarius, and external to, but somewhat below, the tentaculo-ethmoidalis. The first change noticeable is that the ventro-external fibres pursue a (very short) course of their own, and pass straight from the latero-external to the ventro-external fascia—thus giving rise in dissection to an appearance as if the muscle consisted of two divisions. The anterior division of the copulo-tentaculo-coronarius lies in a depression on the outer surface of this portion of the muscle. As the transversus oris passes forwards its fibres converge somewhat, and it now lies almost directly between the two muscles mentioned above, the latter being respectively external and internal to it (cp. fig. 10). Not much of it now appears on the lateral surface of the snout, and still less on the ventral surface. In front of this, however, it

again becomes increasingly evident on the surface, both laterally and ventrally, and continues so for the remainder of its course; and as the tentaculo-ethmoidalis narrows down in front, the transversus oris expands in the transverse plane. The dorso-internal fibres now pass upwards, and are inserted (? origin) into the entire internal surface of the sheath of the *first* tentacular cartilage after the latter has entered the contour of the snout, whilst the remaining fibres pass straight forwards and are inserted into the dorso-external surface of the sheath of the *second* tentacular cartilage, also within the contour of the snout (= transverse labial cartilage).

As far as the sections are concerned, the above represents a clearly defined and independent muscle, the object of which is to assist in the varied movements of the first and second tentacles. It therefore may be said to represent the transversus oris *sensu stricto*, although, of course, it is not a transverse muscle. There are, however, closely associated with it, two other muscle bundles, each of them strictly a separate muscle, but which I describe here, as they are evidently all included under P. FÜRBRINGER'S transversus oris. The independence of these and other muscles will be reconsidered in the concluding morphological part of this work.

Ventral Commissure (fig. 10).—Arises as follows:—(*a*) some fibres from the ventro-internal surface of the sheath of the root of the second tentacular cartilage (transverse labial); (*b*) a few fibres from the internal fascia of the anterior division of the copulo-tentaculo-coronarius; (*c*) the majority of the fibres from the ventro-internal fascia of the transversus oris, *sensu stricto*. I do not think the latter muscle contributes any fibres direct to this commissure, but the association between them is very close. This transverse commissure is seen on the ventral surface at the anterior end of the snout on removal of the skin, and passes without a break from the origin of one side to that of the other, *ventral* to the transverse labial cartilage and the anterior extremity of the tentaculo-ethmoidalis.

Dorsal Pseudo-Commissure.—I thought at first that this was another true transverse commissure, but a careful examination of the sections reveals that the two muscles only meet at a median linea, and that no fibres pass continuously from one side to the other. It "arises" from the dorso-internal surface of the sheath of the root of the second tentacular cartilage (transverse labial), and passes downwards, backwards, and inwards, at first lying over and closely associated with the ventral commissure, and immediately below the nasal tube. It, however, extends further back than the ventral commissure, so that it crosses the latter diagonally and appears by itself behind it. The two muscles meet at an angle at a connective tissue linea situated at the middle line just below the nasal tube. As the transverse labials pass backwards to fuse at the median line with the subnasal bar, the pseudo-commissure lies *dorsal* to them, and the more posterior fibres are "inserted" into their dorsal surface at the point of fusion not far from the middle line.

The transversus oris is not separated by J. MÜLLER, who confuses and describes it

with the tentaculo-ethmoidalis. P. FÜRBRINGER believes that its function is to assist the suctorial action of the mouth, whilst that of the transverse commissure is to approximate the second tentacles. It is, however, questionable whether the mouth of Myxinoids is ever suctorial, and further, the transverse commissure extends beyond the base of the second tentacles.

6. *M. nasalis.* (Figs. 3, 8, 9, 11, *nas.*)

J. MÜLLER, *Zurückzieher der Nasenöffnung* (p. 258).
„ *Zurückzieher der äussern Nase* (p. 322).
„ *Zurückzieher der Schnautze* (p. 323).

Arises by two small fasciculi largely from the tough membrane enclosing the roof (external superficial fascia), but also from that covering the side of the nasal chamber at about the anterior half of the latter. It passes straight forwards, partly obscuring the nasal chamber and nasal tube, and is inserted as follows:—(*a*) into the internal process of the *lateral* labial cartilage (cp. Part I., figs. 1 and 2, and present Part, fig. 3); (*b*) into the ventral longitudinal bar connecting the anterior nasal rings. This bar is also connected by ligament with the process above, in this respect differing from *Bdellostoma* according to AYERS and JACKSON, who state that the process is joined by ligament to the nasal tube, but not to any cartilages of the tube; (*c*) into the lateral wall of the anterior extremity of the nasal tube itself, in front of the third nasal ring; (*d*) into a dorsal forwardly-directed process from the second nasal ring. This process is not always found, and may be present on one side and not on the other. It is figured by POLLARD;* (*e*) joins with the vertical ethmoideo-nasalis (cp. fig. 3), and is inserted into the first nasal ring and the side wall of the external nasal opening. This is the only insertion mentioned by P. FÜRBRINGER.

For the greater part of its length the M. nasalis is seen to consist in transverse section of two large fasciculi—a dorsal triangular one and a larger ventral oval or quadrangular one. The whole forms in section a large triangular mass, with its base resting on the dorsal edge of the tentacularis posterior (behind) and on the outer dorsal surface of the palato-ethmoidalis superficialis.

According to J. MÜLLER, the muscle is very differently related in *Bdellostoma.* He states that it arises from the palatine bar, and is inserted not only into the anterior end of the nasal tube, but also into the *transverse* labial cartilage. In *Myxine* it does not even approach either of these cartilages.

The function of the nasalis, when not neutralised by the ethmoideo-nasalis, would be to draw the nasal opening and the lateral labial cartilage backwards and somewhat upwards.

* *Zool. Jahrb.*, Abt. Morph., viii., fig. 11.

7. *M. ethmoideo-nasalis.* (Figs. 3, 11, *e. n.*)

J. MÜLLER, *Compressor narium* (p. 259).

A very small cylindrical muscle, with its fibres somewhat twisted like a rope in one dissection (cp. fig. 3). Its origin, as seen by dissections, is indefinite. Many, if not most, of the fibres arose from the ventral convex protuberance at the anterior extremity of the subnasal bar (cp. Part I., fig. 1). A number of fibres, however, *appear* to be contributed by the transversus oris, of which the present muscle may conceivably be a differentiated portion. It passed vertically upwards in a curve, bent externally round the origin of the second tentacle (J. MÜLLER, by mistake, says the first), and is inserted, after a very short course, partly into the first nasal ring above the ventral anterior process, and partly into the lateral wall of the nasal tube between rings one and two, whilst the most posterior fibres intermingled with the insertion of the nasalis, as mentioned under that muscle.

In the sections the following conditions are found. The posterior fibres arise from about the dorsal third of the fascia between the opposed surfaces of the transversus oris and the tentaculo-ethmoidalis. These fibres are tightly wedged in between the two latter muscles, but a very careful examination failed to convince me that there is any mingling of the fibres of the three muscles. The posterior fibres of the ethmoideo-nasalis pass almost straight upwards, but slightly forwards, and are inserted into the dorsal-lateral wall of the nasal tube in front of the second nasal ring. These are the fibres that are confused at their insertion with the anterior extremity of the insertion of the nasalis (*q.v.*). As the tentaculo-ethmoidalis dies away in front, the ventral end of the ethmoideo-nasalis bends sharply inwards, almost at a right angle, under the dorsal pseudo-commissure of the transversus oris, to take its origin from the dorso-lateral margin of the zone of soft cartilage at the anterior extremity of the subnasal bar, just at the fusion with the transverse labial and between the origin of the tentaculo-ethmoidalis (below) and the "insertion" of the pseudo-commissure (above). On the right side the origin extended further forwards on to the external margin of the transverse labial. In front, the insertion leaves the dorso-lateral wall of the nasal tube and passes on to the dorsal margin of the first nasal ring at the point where this fuses with the forwardly-directed lateral process (cp. Part I., fig. 1). The insertion finally passes forwards as a definite narrowing bundle over the external surface of the first nasal ring on the ventral margin of the same, into which it is inserted right up to its anterior extremity, lying just below the first ring at this part of its course.

The contraction of the two ethmoideo-nasalis muscles is stated by P. FÜRBRINGER to press the first (= my second) tentacles against the nasal tube, and thus close the nasal opening; but J. MÜLLER asserts, and with more probability, that it presses the anterior end of the nasal tube against the subnasal bar, and closes the nasal opening in that way. Moreover, in my sections the muscles arise so far back that the second tentacles could not possibly be affected in the way FÜRBRINGER supposes.

8. *M. palato-ethmoidalis superficialis.* (Fig. 3, *p. e. s.*)

J. MÜLLER, *Zurückzieher der knöchernen Stütze der Schnautze* (p. 258). *Zurückzieher der Schnautzenstütze* (p. 322).

Superficially a powerful fan-shaped longitudinal muscle, with the handle directed forwards. It is roughly triangular in transverse section, the outer or superficial area representing the base of the triangle, with the apex directed inwards towards the subnasal and palatine bars. In the sections, about the middle third of the muscle was divided into two distinct portions—a dorso-horizontal plate-like portion and a ventral much larger portion. It is covered largely by the tentacularis posterior, but its dorso-external margin may appear on the surface between the latter muscle and the nasalis.

The palato-ethmoidalis superficialis has a very broad origin, as follows:—(*a*) from the lateral wall of the nasal capsule. As shown in fig. 3, this part of the origin extended back under the eye for a short distance on to the cranium. In the sections it passed back over, but not behind, the eye on the left side, but on the right side it terminated in front of the eye; (*b*) from the external fascia of the dorso-anterior border of the copulo-quadratus profundus; (*c*) from the dorso-external fascia of the palato-coronarius; (*d*) from the posterior third of the cornual cartilage (in a dissection). Except perhaps for a very few fibres from the root of the cornual cartilage, this was certainly *not* the case in the sections, the present muscle being excluded from the cartilage by the insertion of the palato-ethmoidalis profundus; (*e*) from the external margin of the anterior half of the palatine bar (dissection). In the sections this part of the origin is from the anterior three-fourths. Posteriorly, where the muscle fibres themselves do not reach the bar, the internal apex of the muscle is connected with it by a short strong ligament. The more superficial fibres are represented by *a* and *b* above, and the deeper fibres by *c*, *d*, and *e*, these latter being the deepest and constituting the apex of the triangle.

In *Bdellostoma*, according to J. MÜLLER, the palato-ethmoidalis superficialis arises from the palatine bar only, whilst in *Myxine* P. FÜRBRINGER states that it arises from the *posterior* half of the bar and from the "lateral region of the skull."

The fibres of the palato-ethmoidalis superficialis pass forwards, rapidly converging, and were inserted, in a dissection, into about the anterior third of the subnasal bar. P. FÜRBRINGER says the middle third. In the sections the insertion covered exactly one-half of the extreme length of the bar, *i.e.* it extended through 130 sections, whilst the bar itself passed through 65 sections in front of and 65 behind it. Posteriorly, the muscle is inserted into about the dorsal half of the lateral surface of the bar, the ventral half being occupied by the origin of the palato-ethmoidalis profundus. As, however, the latter muscle dies away, the superficialis extends over the whole of the lateral surface of the bar, but at its anterior extremity it is again excluded from the lower part of the lateral surface by the commencement of the insertion of the copulo-ethmoidalis.

According to P. FÜRBRINGER, the palato-ethmoidalis superficialis produces a dorsal flexion of the subnasal bar and a retraction of the dorsal margin of the mouth, in order to bring the median tooth into a favourable position for piercing the prey.

9. *M. palato-ethmoidalis profundus.* (Figs. 3, 10, 11, *p. e. p.*)

J. MÜLLER, *Pyramidale Muskel der Schnautze* (p. 259). *Compressor der Mundhöhle* (p. 332).

Lies largely under the palato-ethmoidalis superficialis. It is a short but powerful muscle, and appears on the roof of the mouth (covered, of course, by the mucosa), as shown in fig. 10. Of this muscle ALLIS says*: "This latter muscle I find, however, in *B. dombeyi* as two wholly separate muscles, one lying dorsal to the other, and the two crossing each other at an angle. Both muscles extend from the nasal bar to the cornual cartilage, and they both must act as adductors of that cartilage, drawing it toward the nasal bar." There are certainly clear indications anteriorly of the division mentioned by ALLIS (cp. fig. 11), but behind, the two parts of the muscle are generally not separable. In front, however, the anterior, inner or ventral, division passes obliquely backwards, and the posterior, outer or dorsal, division obliquely forward. Hence, as ALLIS states, the fibres cross at an angle. In one specimen I found the two divisions entirely distinct, as in *B. dombeyi*. It is not easy to study this condition in transverse sections, but in a series of vertical longitudinal sections I found the muscle consisting of a thin postero-dorsal portion and a more extensive and greatly thicker ventral portion, the distinction being observable throughout the entire extent of the muscle. I believe, however, it is only another expression of the tendency noticeable in many of the muscles of Myxinoids for the fibres to collect into large separate divisions, which might almost be described as separate muscles. Compare, for example, the velo-quadratus muscle, where there are three of these divisions.

The palato-ethmoidalis profundus arises from the lateral (in front, ventro-lateral) and ventral surfaces of about the posterior two-thirds of the subnasal bar. P. FÜRBRINGER says the posterior half, and J. MÜLLER the *whole* in *Bdellostoma*. In the sections it works out as the posterior two-thirds exactly. The fibres of the muscle pass outwards and somewhat downwards, and converge from both extremities to be inserted into the dorso-internal surfaces (median margin—P. FÜRBRINGER) of slightly more than the posterior two-thirds of the cornual cartilage opposite the "origin" of the copulo-palatinus. In the sections the insertion had precisely the same extent.

Since the area of origin is greater than that of the insertion, both as regards vertical surface and longitudinal extent (in the latter respect extending over 172 sections as against 98), it follows that all the fibres arising from the subnasal bar cannot be inserted into the cornual cartilage. Posteriorly a large number of them are inserted into the ventral fascia of the muscle extending transversely from the cornual cartilage to the median pad of soft pseudo-cartilage described on p. 765 of my first Part.

* *Op. cit.*, p. 272.

This pad of tissue commences about 50 sections in front of the posterior extremity of the palato-ethmoidalis profundus, and its tapering non-cartilaginous dorsal portion extends upwards from the mucosa like a wedge towards the subnasal bar, separating the two profundus muscles in the median plane for about 25 sections. The pad does not quite reach the subnasal bar, except where it bends upwards and backwards, and is connected by fascia with its posterior extremity, as described in my first Part. The two profundus muscles are closely opposed to the pad, but I do not think they are attached to it, as stated in my first Part.

P. FÜRBRINGER figures the present muscle as inserted into the *entire* length of the cornual cartilage, and states further that some fibres are inserted into the palatine bar itself. My dissections and sections agree with neither of these statements, but the latter is probable enough, as the fibres extend right to the boundary between the two cartilages in question. In *Bdellostoma*, according to J. MÜLLER, the muscle has a strongly pyramidal shape, the apex of the pyramid being inserted into the cornual cartilage. In *Myxine* the insertion is, on the other hand, a very broad one, although narrower than represented by P. FÜRBRINGER.

The action of the profundus muscle, by approximating the two cornual cartilages, and consequently the lateral labials, is to compress the mouth cavity laterally.

10. *M. quadrato-palatinus.* (Fig. 11, *q. p.*)

J. MÜLLER, *Anzieher des Schlundkorbes* (p. 261).

A moderately strong triangular-shaped muscle, with the apex directed forwards, and covered by the palato-coronarius in front. Internally it abuts on the lateral roof and dorso-lateral wall of the mouth.

The quadrato-palatinus arises by a broad origin (forming the base of the triangle) from the ventral margin and internal surface of the pterygo-quadrate from immediately behind the transverse zone of soft cartilage separating it from the palatine up to the similar zone of soft cartilage at about the middle of the inferior process of the pterygo-quadrate (*i.e.* mostly from the anterior process of the latter). P. FÜRBRINGER gives the origin from the lateral margin only, but both my dissections and sections support the statement of the origin given above. In the sections on the left side the origin extended back to the posterior extremity of the inferior process, and thus the muscle arose from the entire length of the anterior and inferior processes, but on the right side it did not go back so far, though further than described above.

The fibres of the pterygo-quadrate pass forwards, strongly converging, and merge into a long powerful tapering tendon which arises from the ventral surface of the muscle and courses straight forwards (but slightly inwards) under the palato-coronarius and opposed to the lateral roof of the mouth, to be inserted into the latero-ventral surface of the anterior extremity of the palatine bar, *i.e.* just posterior to where it fuses

with the cornual cartilage. In the sections it was inserted into the palatine bar just behind the palatine commissure. Shortly behind its insertion the tendon, in the sections, gave off from its external margin a small slip which passed internally under the parent tendon to some loose tissue connected with the roof of the mouth not far from the median line.

The function of this muscle will be to bend the palatine bar downwards. In *Bdellostoma* J. MÜLLER curiously describes the insertion of the muscle as the origin, and states that it draws the pharyngeal basket forwards. In *Myxine* he ascribes to it the opposite (and surely the correct) function.

11. *M. palato-coronarius.* (Fig. 11, *pl. c.*)

J. MÜLLER, *Zurückzieher des Mundrandes oder der Mundknorpel* (p. 258). *Zurückzieher des Mundes* (p. 330).

A fairly strong muscle, covered externally by the copulo-quadratus profundus, and having two heads—a large external (*pl. c.*) and a smaller internal. Between the two heads courses the R. externus of the maxillaris of P. FÜRBRINGER. According to J. MÜLLER there is only one head in *Bdellostoma.*

External Head.—Commences at the posterior portion of the zone of soft cartilage between the palatine bar and the anterior process of the pterygo-quadrate by some fibres from the external rim of this region, and from thence the origin passes obliquely forwards and inwards on to the ventral surface—first of the zone of soft cartilage above, and then on to the same surface of the palatine bar to meet the internal head, which it does near the internal rim of the cartilage. The two heads are now spread over the entire outer and ventral surfaces of the palatine bar at this region. A short distance in front of the zone of soft cartilage the muscle begins to be detached from the palatine bar, the separation commencing externally, and extending inwards and forwards until completed. The fibres of the external head pass downwards and forwards towards the pad of soft pseudo-cartilage at the anterior end of the basal plate, the fibres somewhat converging as they go.

Internal Head.—Arises at the above-mentioned region of the zone of soft cartilage, but below, internal and quite distinct from it, mostly from the ligamentous sheet connecting the palatine region with the hypophysial plate about half way between these two cartilages. The head then passes forwards, outwards, and upwards to meet the external head, and where the junction is effected a few or more fibres are contributed to this head from the inner ventral surface of the palatine bar immediately in front of the zone of soft cartilage. It is difficult to ascertain how much is contributed by the palatine bar, as the two heads here are by no means easily distinguishable either in dissections or in the sections. The fibres follow the same course as in the external head, but are completely covered by the latter in a lateral view.

The two heads pass into a common and very short but powerful tendon which arises from the ventral surface of the opposed heads, but chiefly from the external ventral surface, and which in one dissection was inserted into the pad of soft pseudo-cartilage at the anterior extremity of the external bar of the anterior segment of the basal plate, dorsal and external to the lateral labial cartilage as it was winding over the pad to fuse with the external bar. There was no union of the two heads before passing into the tendon, such as described by P. FÜRBRINGER. In another specimen, however, it was inserted largely into the dorso-posterior surface of the lateral labial itself as it was passing over the pad. In *Bdellostoma*, according to ALLIS, the insertion is into "the lateral labial cartilage, or in the tissues near that cartilage." P. FÜRBRINGER states that the tendon is inserted into the lateral labial only, which, however, he did not recognise to be cartilaginous at this region. J. MÜLLER also gives this insertion in *Bdellostoma*. In my sections I find that the tendon is large, diffuse (not easily defined), and attached to the surrounding fascia. It passed at once on to the dorsal surface of the pad of pseudo-cartilage, dorsal and *largely posterior* to the lateral labial (cp. fig. 1 of my first Part), which it certainly did not reach. Further, the two heads fused before reaching the tendon (as described by P. FÜRBRINGER), and otherwise the separation of the two heads was very difficult, although their origins were perfectly distinct. The indefiniteness of the tendon and its connection with the surrounding fascia would seem to explain the discrepancies in the statements above.

The palato-coronarius draws the anterior extremity of the basal plate, and hence the ventral margin of the mouth upwards and backwards.

12. *M. copulo-tentaculo-coronarius.* (Figs. 3, 9, 10, 11, *cp. t. c.*, *cp. t. c'.*, *cp. t. c''.*)

J. MÜLLER, *Zweiköpfige Herabzieher des Mundes* (p. 259).
P. FÜRBRINGER, *Copulo-tentaculo-coronarius + Tentacularis anterior* (pp. 12 and 17).

A curious and complex muscle, the anterior division of which is regarded by P. FÜRBRINGER as a separate muscle, having an independent origin from the base of the fourth tentacular cartilage, and called by him the tentacularis anterior. I have, however, invariably found, both in dissections and sections, that the latter is, with the exception of a few fibres, simply the forward continuation of the first head of the copulo-tentaculo-coronarius, and hence cannot be separated from it.

The copulo-tentaculo-coronarius arises as a first or principal head (*cp. t. c.*) from the median border of the external bar of the anterior segment of the basal plate at about the middle of its length, and some fibres also from the tough fibrous tissue connecting the external and internal bars (fig. 11). P. FÜRBRINGER states that some fibres arise from the outer margin of the internal bar. In the sections this head is reinforced by a small second head from the ventro-external fascia of the origin of the external head of the copulo-ethmoidalis, and which passes forwards external to the dorsal portion of

the first head, to more or less fuse with it. The posterior division (below) is formed in the sections by the fibres of this second head + the *superficial* fibres of the principal head. Also new fibres are contributed internally which arise from the internal fascia of the latter. The fibres of the first head pass straight forwards, almost parallel at the latero-ventral margin of the mouth, and opposed to the external surface of the basal plate until they reach the region of the fourth tentacle, where they are shuffled into two fairly large bundles. One of these, the *posterior division* (*cp. t. c'.*) takes an upward bend, and passes at once on to the root of the fourth tentacle just above where the latter is connected by a horizontal ligamentous sheet with the pad of soft pseudo-cartilage at the anterior end of the external bar of the anterior segment of the basal plate. As shown in figs. 3, 9, and 11, the fourth tentacle rests on the external surface of the ventral region of this muscle, and some of the external fibres passing up to it may have a separate origin from the external fascia of the principal head. A variable number of fibres arise from the cartilage of the fourth tentacle itself, and fuse with the posterior division, thus constituting another small head for the muscle. The posterior division now passes upwards, forwards, and inwards, and joins with a bundle arising from the anterior surface of the root of the third tentacle, and coursing straight upwards. This bundle in dissections only seems to *accompany* the posterior division, and not to fuse with it. In another specimen there was a second and posterior bundle arising from this tentacle. The anterior one (*i.e.* the one above) was certainly independent of the posterior division, and the posterior one also seemed distinct from, although closely opposed to it. This point is difficult to determine in transverse sections, but in a series of longitudinal vertical sections I find the head from the third tentacle comprised of anterior and posterior bundles as above, which were closely opposed to the posterior division at their insertion, but certainly did not fuse with it. These bundles, therefore, do not, strictly speaking, constitute further heads of the copulo-tentaculo-coronarius, but form small independent muscles like the coronarius, the function of which will be to move the third tentacle in the longitudinal vertical plane.

Both the posterior division and the bundle or bundles from the third tentacle are inserted into the lateral labial at the place where this receives the cartilage of the third tentacle, the latter into the ventral surface, and the former, which is related to the coronarius, as elsewhere described, into its outer ventral and inner surfaces, and also into the posterior surface of the root of the third tentacular cartilage itself.

The *anterior division*, or *Tentacularis anterior* of P. FÜRBRINGER (*cp. t. c''.*), passes forwards and upwards, largely internal to the posterior division, and internal to the fourth and third tentacular cartilages. It is not mentioned by J. MÜLLER in *Bdellostoma*. It gives off at its origin a bundle of fibres which passes upwards to the posterior surface of the third tentacular cartilage (cp. fig. 3), and its ventral surface is reinforced by some fibres which arise from the root of the fourth tentacular cartilage, and which therefore represent another small head of the copulo-tentaculo-coronaris.

The subsequent course of the anterior division is best dissected in specimens that have been preserved in an acid medium, such as Perenyi's fluid. It passes forwards and upwards as a compact bundle in a gentle curve at the lateral margin of the mouth, and is finally inserted into the ventro-external surface of the root of the second tentacular cartilage, or what is called by AYERS und JACKSON the transverse labial cartilage.

The copulo-tentaculo-coronarius has obviously a complex function, which can only be ascertained by direct experiment. It will, however, at least retract the lateral labial and the second, third, and fourth tentacles. In *Bdellostoma*, according to J. MÜLLER, the head from the fourth tentacular cartilage is wanting, and the origin of the first or principal head is from the *internal* bar of the anterior segment of the basal plate.

13. *M. coronarius*, F.J.C. (Figs. 3, 11, *co.*)

P. FÜRBRINGER, "*Endinsertion*" *of the copulo-tentaculo-coronarius* (p. 17).

According to P. FÜRBRINGER this muscle represents the final insertion of the copulo-tentaculo-coronarius, but as I find no connection between these two muscles beyond that which commonly obtains between adjacent muscles, I have separated it under the above name. Its fibres are quite independent, and if we are to regard, for example, the palato-ethmoidalis profundus as a separate muscle from the copulo-palatinus, we cannot describe the present muscle as simply the insertion of another. Its position and relations are also against this.

The coronarius is a very small muscle, with a somewhat curious anatomy. It arises from the *dorsal* surface of the lateral labial cartilage, just behind where the latter fuses with the cartilage of the third tentacle. The origin lies immediately in front of and in contact with the ligamento-cartilaginous connection between the lateral labial and cornual cartilages described on pp. 765–6 of my first Part, and shown (but not lettered) in fig. 2. Cp. also fig. 11 of present Part. This connection, by the way, I now believe to be constant.

At its posterior extremity in the sections, and in one dissection, the coronarius extended downwards from its dorsal position on the lateral labial over the *external* surface of this cartilage, and at the same time the insertion of the posterior division of the copulo-tentaculo-coronarius rose upwards from its ventral position on the same, also over its external surface, to meet it. A careful examination of both sides of two series of sections differently stained has, however, convinced me that the latter fibres are only inserted into the external *fascia* of the coronarius, and that the fibres of the two muscles are quite independent. Further, in two dissections, the muscles were obviously distinct, and almost at right angles to each other. And even if the fibres of the two were here continuous, only a small portion of the coronarius would be accounted for, and by far the major portion would have an origin of its own from the lateral

labial, and would thus, on P. FÜRBRINGER's view, constitute still another head of the copulo-tentaculo-coronarius.

In front of the origin the muscle gradually tapers down, passes upwards and forwards closely opposed to the dorso-posterior surface of the lateral labial cartilage, and is inserted into the same surface of this cartilage immediately behind the internal process. It is difficult to assign any function to this insignificant muscle, except that it may assist in manipulating the first tentacle, seeing that its posterior end is fixed.

14. *M. copulo-ethmoidalis.* (Figs. 3, 9, 10, 11, *c. e.*, *c. e'.*, *c. e''.*).

J. MÜLLER, *Herabzieher der knöchernen Schnautzenstütze* (p. 259).

A stout, powerful muscle arising by two heads—an antero-external (*c. e.*) and a postero-internal (*c. e'.*). The former head was not distinguished by J. MÜLLER or P. FÜRBRINGER, but I find it invariably present both in dissections and sections.

The *external head* arises from the superficial fascia at the region of the antero-dorsal border, and also from that of the antero-internal margin, of the copulo-palatinus. It appears on the surface immediately in front of the latter muscle and of the anterior border of the obliquus muscle, and below the cornual cartilage. Its fibres pass upwards, forwards, and inwards in an arch underneath the cornual and lateral labial cartilages, and soon unite with the other head to form the antero-ventral portion of the insertion.

The *internal head* arises medianly to the preceding, mostly from the external surface of the bulb of soft pseudo-cartilage at the anterior end of the external bar of the anterior segment of the basal plate, but some of the ventro-external fibres arise from the dorso-external surface of the hard cartilage of the anterior extremity of the external bar itself. The fibres of the internal head pursue a similar course to those of the external head, and form the postero-dorsal portion of the insertion. The lateral labial cartilage lies in a depression on the dorsal surface of this head.

As the copulo-ethmoidalis passes forwards it becomes greatly compressed from side to side, and bent in the form of a vertical crescent with the concavity directed externally. It appears on the surface of the roof of the mouth (covered, of course, by the mucosa), as shown in fig. 10, *c. e''.*, and is inserted by about the central portion of the inner or convex surface into the entire extent of the lateral surface of the subnasal bar, from about the posterior extremity of the anterior soft cartilage portion to the anterior end of the insertion into the same of the palato-ethmoidalis profundus. All the fibres are, however, not inserted into the subnasal bar, since there are some inserted into the fascia immediately above and below this cartilage, and these were in fact, in the sections, continued forwards somewhat in front of the fibres inserted into the the bar.

The function of the copulo-ethmoidalis is to compress the mouth cavity vertically

by approximating the basal plate and subnasal bar. This will facilitate the rasping action of the ventral teeth.

15. *M. hyo-copulo-glossus.* (Fig. 11, *h. c. g.*)

J. MÜLLER, *Beuger des Zungenbeins* (p. 249). *Beuger des ersten und zweiten Gliedes des Zungenbeins* (p. 332).

A powerful flat longitudinal muscle which arose in a 34½ cm. Hag from the anterior surface of the most ventral 2½ mm. of the first branchial arch internal to the insertion here of the hyo-copulo-palatinus, but in another specimen of the same size from the most ventral 3½ mm. This origin from the first branchial arch is wanting in *Bdellostoma* according to J. MÜLLER. In the sections the most dorsal fibres were so intimately associated with the insertion here of the hyo-copulo-palatinus that I am doubtful whether they can be separated. Some fibres also may arise from the middle segment of the basal plate anterior to where the first branchial arch fuses with it. The fibres of the muscle at first pass forwards and slightly upwards, almost parallel, but slightly converging, and alongside and external to the middle segment of the basal plate. Opposite the anterior border of the broad forward ventral process from the hyoid arch described on p. 764 of my first Part, and shown in fig. 2, and which I now believe to be of general occurrence (cp. fig. 11 of present Part), the muscle on the right side in the sections received a small reinforcing head from the *inner* surface of the membrane connecting the pharyngeal basket with the basal plate. This was also suggested on the left side. The fibres now fan out and take a more dorsal course, and are inserted partly into the fascia investing the mucous membrane of the lateral diverticulum of the mouth at the base of the dental apparatus (opposite about the dorso-middle region of the latter), but also largely into the loose ventral fascia between the dental skeleton and the basal plate and which is attached in front to the mucosa of the ventral region of the mouth. The pull on the ventro-lateral mucosa naturally retracts the fourth tentacle also, and this is doubtless the basis for the statement by J. MÜLLER and P. FÜRBRINGER that the "tendon" of this muscle is inserted into the fourth tentacle. In another specimen a few of the most posterior fibres extended on to the mucosa of the *roof* of the mouth, and this was observed in sections also.

Opposite the antero-ventral angle of the belly of the hyo-copulo-glossus, which here sends downwards a small projection, there is a wide strand of fatty connective tissue, which passes upwards and inwards to fuse with the stout membrane connecting the anterior and posterior arches of the dental plate about midway between these two cartilages. It is itself not ligamentous, but in the sections it assisted in transmitting an inconsiderable bundle of elastic fibres which arose from the tissues around the posterior arch of the dental plate and passed forwards (fused in front of the "tether" with the ventral free margin of the "tendon" of the hyo-copulo-glossus) to be inserted into the dorsal margin of the guiding rail on the anterior segment of the basal plate

(see Part I. pp. 772–3), but which had no *direct* connection with the present muscle. The strand above is the transverse tendon or "tether" of J. MÜLLER and P. FÜRBRINGER, and its object seems to be to provide a pathway under the control of the present muscle for the passage of nerves and blood-vessels to and from the "tongue." Such a movable bridge is, of course, necessary, as the position of the "tongue" is not fixed.

According to P. FÜRBRINGER, the larger part of the fibres of the hyo-copulo-glossus pass into a tendon which is inserted into the ventral [?] surface of the internal bar of the anterior segment of the basal plate throughout its entire length, a small slip being also despatched to the base of the fourth tentacular cartilage. This agrees substantially with J. MÜLLER's account of *Bdellostoma*, and I therefore feel diffident in questioning its accuracy. Nevertheless I am more than doubtful whether what these authors describe as the anterior tendon of this muscle is not too diffuse and extensive to represent a true tendon of a muscle, and I cannot regard it as other than a portion of the general fascia. It is true that a careful examination of the sections reveals its ventral margin fusing with the dorsal border of the guiding rail of the anterior segment of the basal plate, and in front of this with the large pad of soft pseudo-cartilage on the dorsal surface of the anterior extremity of the same, but it is certainly *not* connected with the fourth tentacle. Its principal relation is undoubtedly to the mucosa of the mouth as above described, whilst in front of the basal plate it loses its identity by fusing first with the external fascia of the copulo-palatinus and then with the ventro-external fascia of the first or principal head of the copulo-tentaculo-coronarius—thus indicating again that it is only a portion of the general fascia. FÜRBRINGER indeed seems to have been here influenced by MÜLLER's description of the muscle.

An important function of the hyo-copulo-glossus is stated by FÜRBRINGER to be that it acts as a tether to the dental apparatus, *i.e.* prevents by its transverse "tendon" the "tongue" from travelling too far in either direction. Here, again, FÜRBRINGER has overlooked the fact that as the play of the latter is necessarily limited by the looseness of the mucosa of the floor of the mouth, such a function is surely superfluous. A much more reasonable explanation of the "tether" is the one I have given above. FÜRRRINGER also states that the attachment of the "tether" ventrally at a position intermediate between the anterior and posterior borders of the dental apparatus would assist the pull of the protractors in toppling the latter out of the mouth by acting as a fulcrum. Further, when the "tether" is fully extended forwards, the pull of the hyo-copulo-glossus is said to reinforce the backward drag of the longitudinalis linguæ until the "tether" has swung backwards behind the anterior extremity of the belly of the former muscle, when it is stated to play a passive rôle, and simply to prevent the dental apparatus passing too far backwards. But here also it seems idle to suppose that a very powerful muscle such as the longitudinalis linguæ requires any assistance, and still more so that a strand of fatty areolar tissue is capable of arresting its action. The "tongue," of course, passes as far backwards as the anterior mucosa of the mouth and its related skin will allow it, and no further.

The real function of the hyo-copulo-glossus I believe to be that it acts as the antagonist to the copulo-glossus superficialis. We shall see that the latter muscle evaginates the mucosa anterior to the "tongue" by a ventro-lateral pull on it; and as the present muscle is also inserted into the ventro-lateral mucosa, it will naturally pull the latter back into the mouth when the "tongue" is withdrawn. It will thus have precisely the same relation to the longitudinalis linguæ as the copulo-glossus superficialis has to the copulo-glossus profundus.

16. *M. copulo-glossus superficialis.* (Figs. 3, 9, *c. g. s.*, *c. g. s'.*, *c. g. s''.*)

J. MÜLLER, *Äussere Vorzieher der Zunge* (p. 250).
„ *Erste* „ „ (p. 323).
„ *Oberflächlicher* „ „ (p. 331).

A long somewhat powerful muscle, for the greater part of its course closely related to the lateral head of the copulo-glossus profundus. It arises from the dorsal margin of the posterior segment of the basal plate at about the beginning of the taper, *i.e.* at the posterior end of the anterior third, ventral and somewhat internal to the origin of the copulo-quadratus superficialis, with which it is somewhat closely associated by its dorsal border. In *Bdellostoma*, according to J. MÜLLER, it arises by *two* heads from the *posterior* end of the basal plate. Its posterior half is hidden by the lateral head of the copulo-glossus profundus. Its anterior half comes to the surface between the above two muscles (but is, of course, covered externally by the obliquus), and continues its course downwards and forwards in a slight curve, becoming laterally flattened and fan-shaped as it proceeds. In front it passes abruptly by a wide irregular border a short distance behind the ventral margin of the mouth into a wide, thin, but strong tendon, which fuses completely with that of the other side to form a concave posterior border. This tendon passes straight forwards in the mid-ventral region, and gives off one largish median (*c.g.s'.*) and a few fine lateral bundles, all of which fuse with the skin immediately behind the ventral margin of the mouth, and in front of the anterior border of the obliquus. The median slip above is also described by J. MÜLLER in *Bdellostoma*, but P. FÜRBRINGER missed it in *Myxine*.

The tendon narrows slightly as it approaches the mouth, but on reaching the latter it fans out laterally, and its central portion, after giving off the median slip to the skin above mentioned, bends sharply round the anterior margin of the internal bar of the anterior segment of the basal plate into the mouth, external to the tendon of the copulo-glossus profundus, and begins to pass backwards towards the dental apparatus (this, of course, when the latter is retracted).

The subsequent fate of the tendon is not only very difficult to ascertain by means of dissections, but this method is actually misleading—at all events as far as preserved material is concerned. I have therefore worked it out in one series of transverse and another of vertical longitudinal sections. However, by splitting the basal plate

along the middle line and pinning the halves out laterally, the tendon is seen to lose its identity very quickly. The lateral portion fans out considerably, and fuses with the ventro-lateral mucous membrane at the aperture of the mouth. This portion of the tendon gives off, according to J. MÜLLER and P. FÜRBRINGER, a small lateral bundle for the cartilage of the fourth tentacle. I have found this bundle (*c. g. s″.*), and have traced it into the fascia at the base of and behind the fourth tentacle, but could not satisfy myself that any of its fibres were *continuously* connected with the cartilage of the tentacle itself. The more median portion of the tendon is apparently quickly lost on the mucous membrane of the floor of the mouth. J. MÜLLER, however, states that it is attached to the anterior margin of the " tongue " cartilage ; and P. FÜRBRINGER asserts that it *splits* into two portions, which are inserted one on each side at the anterior lateral region of the dental plate, *i.e.* lateral to the insertion of the tendon of the copulo-glossus profundus. Dissections certainly favour the statements of both these writers as regards the insertion into the dental plate.

Now with regard to the sections. In transverse sections the forward course of the tendon from the muscle belly to the ventral margin of the mouth confirms what has already been stated from dissections. As, however, the tendon bends round the anterior edge of the basal plate two stout longitudinal sheets (*i.e.* one on each side) are given off at the boundary of the lateral and median portions of the tendon, and these pass almost vertically upwards, but at first somewhat medially, and are inserted into the tough fibrous submucosa of the *lateral* wall of the median ventral longitudinal diverticulum of the mouth. The median portion of the tendon, after it has rounded the basal plate, is at once inserted into the same tissue of the *ventral* wall of the diverticulum. The tendon fibres can be traced back on the ventral wall of the diverticulum for some little distance, but they are undoubtedly lost before the tongue skeleton is reached. As, however, the connective tissues of the teeth and dental plate fuse in places at the region of the anterior border of the latter, any pull on the mucous membrane is necessarily transmitted to the dental plate. Nevertheless it is quite clear that the tendon of the copulo-glossus superficialis is *not inserted into the dental plate.* The lateral slips, supposed to pass to the fourth tentacle, were traced forwards a short distance in front of the bend, but were lost in the submucosa and spongy tissue of the postero-ventro-lateral wall of the mouth without reaching the tentacle in question.

In the longitudinal sections those passing through the median plane show the median portion of the tendon curving round the basal plate anterior and external to the tendon of the copulo-glossus profundus, and at once fusing with the ventral diverticulum of the mouth as above described. Any connection with the dental plate is here out of the question. Further, the complete course of the vertical longitudinal sheets mentioned above is now visible, and we see that the fibres constituting them continue their dorsal course at the sides of the ventral diverticulum of the mouth, curving upwards and finally *backwards* to fuse with the fibrous tissue and the mucosa immediately anterior to the rows of teeth. As these fibres form a great, if not the

greater, part of the tendon, it follows that one important function of the copulo-glossus superficialis is to exercise a forward pull *on the teeth themselves.* Similarly, the other important function of the muscle is to evaginate the antero-ventral mucosa of the mouth.

The lateral slip may be traced forwards in the longitudinal sections up to a short distance behind the base of the cartilage of the fourth tentacle, where it is inserted into the skin and subcutaneous connective tissues. Some fibres of it certainly seemed to pass on to the tentacle itself. It may be, and in fact is the more probable, that the slip only fuses with other connective tissues themselves attached to the tentacle, and thus only secondarily exercises what can, after all, be but a slight control over the motion of this tentacle. The question of fact is not easy to determine, owing to the wealth of fibrous connective tissue which is at this region confused with the tendon of the muscle.

For the function of the copulo-glossus superficialis see the following muscle.

17. *M. copulo-glossus profundus.* (Figs. 3, 9, 11, *c. g. p.* (Part I.), *c. g. p'.*, *c. g. p''.*)

J. Müller, *Innere Vorzieher der Zunge* (p. 251).
„ *Zweite* „ „ (p. 323).
„ *Tiefe* „ „ (p. 331).
Ayers and Jackson, *Protractor of the Dental Plate* (p. 203).

This muscle arises by two heads—a large lateral head (*c. g. p'.*) and a smaller median head (*c.g.p''.*), and is a very long and powerful muscle.

Lateral Head.—May arise from the posterior extremity of the ventral or keel surface of the posterior segment of the basal plate, which surface is not utilised for the attachment of the copulo-copularis muscle. In other specimens, and also in the sections, the fibres extended laterally and posteriorly below the posterior segment, and hence arose from the superficial fascia of the copulo-copularis itself. The posterior segment is, however, represented behind its true termination by the tough fibrous tissue of its sheath forming a median ventral strand. The most superficial fibres of the lateral head meet at the mid-ventral line, and are covered externally by the rectus muscle, whilst the obliquus extends over the whole. The fibres course in a weak arch outwards and forwards and then downwards at the side of the median head, and over the ventral surface of the basal plate, receiving in front in one specimen a small bundle of fibres from the copulo-glossus superficialis. In front, the median border of this head is opposed to the outer border of the rectus.

Median Head.—Has a similar origin to the lateral head, but situated immediately in front of and covered by it. The origin covers the entire surface of the posterior segment at this region, but does not extend beyond it. The median head, however, soon emerges from underneath the lateral one, and its fibres course outwards and forwards in a still weaker curve, the two heads being closely opposed as they pass forwards. At about the middle of their course the rectus muscle passes in between them to reach the middle segment of the basal plate. The two median heads are

slightly separated for a short distance at and in front of their origin, but for the greater part of their course they are closely opposed at the mid-ventral line, so that in some specimens the division is not obvious.

As the two heads approach the ventral margin of the mouth they become more concentrated, and the lateral head assumes a more ventral position, so that just behind the mouth the muscles of both sides form four small compact bundles, consisting of the four distinct heads, two on each side of the mid-ventral line. As the fibres turn abruptly round the anterior margin of the *internal* bar of the anterior segment of basal plate internal to the tendon of the copulo-glossus superficialis (*i.e.* in the relaxed condition), the four heads pass simultaneously into the single median tendon, which is narrowest at this point. The anterior margin of the basal plate is distinctly pulley-shaped—due to the external bars with their pads of soft pseudo-cartilage (cp. Part I., Pl. II. fig. 10), and this confines the tendon to the median portion of the anterior edge of the basal plate. In one specimen the two median heads fused at about the middle of their course, and were finally joined just behind the formation of the tendon by the two lateral heads, the whole mass presenting a bilobed anterior extremity where it passed into the tendon. How much is seen of the tendon ventrally depends, of course, on the position of the dental apparatus.

According to P. Fürbringer, the two heads of each side first fuse up and then pass into a tendon, and the two tendons thus formed unite to form the median tendon. In one series of sections the median head of each side first of all splits into two, the two median halves first fusing up, and the resulting median mass then fusing with the lateral lobes. In this way three muscle masses are seen in transverse section—a large median one, which equals both the median heads, with the smaller lateral head on each side. Subsequently all three fused up, and the single mass so formed finally split into two at its anterior extremity, as mentioned in another case above. The conditions are doubtless subject to much variation.

The tendon of the muscle first appears on the lateral surface of the lateral heads, and then spreads inwards over the *dorsal* surface only of the muscle, to fuse in the middle line, and thus form the median tendon, as seen in dissections. This, after the bend, now passes straight backwards towards the dental apparatus, becoming rapidly wider as it proceeds, and is inserted into practically the entire anterior border of the anterior arch of the dental plate (cp. Part I., fig. 7, *c. g. p.*). As the tendon approaches the dental plate its histology changes, until it resembles a weak form of soft pseudo-cartilage. In fact, the sections irresistibly suggest the view that the anterior arch of the dental plate is merely a chondrification of the tendon of this muscle (cp. Schaffer (16).

P. Fürbringer states, in opposition to the statements of J. Müller, that the tendon of this muscle does not terminate at the anterior margin of the anterior arch, but that it is continued over this on to the posterior arch, and over this again to fuse with the tendon of the *retractor* muscle of the dental apparatus (longitudinalis linguæ).

Examination of a series of vertical longitudinal sections shows that this is true only in a limited sense. The *superficial* fibres of the tendon pass respectively over the dorsal and ventral surfaces of the dental plate, across the fenestræ, and are ultimately continuous with the corresponding fibres of the tendon of the retractor muscle. They do not constitute the *whole* of the fibrous tissue crossing the fenestræ, nor is the soft pseudo-cartilage of the tendons prolonged beyond the particular cartilage into which each is inserted, except to a slight extent in the case of the longitudinalis linguæ. It in fact amounts to nothing more than that there is a fusion (of course inevitable) between the tendons and the fibrous sheath of the dental plate.

We may now conveniently review the *function of the two protractor muscles of the dental apparatus*, but we must first consider the very curious habit on the part of the living Hag of *entirely* protruding its dental plates when either disturbed or stimulated. When a Hag is placed in a quantity of some fixing solution, say formalin, it does not die for some time, but swims rapidly about, showing its teeth or snarling in what is certainly an alarming manner. This is effected by bringing the dental apparatus forwards and then rotating it on its anterior border round the ventral margin of the mouth through an angle of about 115°. The result is that the dental plates, which, when withdrawn, look upwards, with the teeth pointing backwards, now look forwards and somewhat downwards, with the teeth pointing anteriorly. I have succeeded in preserving several specimens with the plates extruded, but do not figure them, as satisfactory figures have already been published by P. Fürbringer and Ayers. This interesting and unique phenomenon was first figured for *Myxine* by Gunner in 1763, and described by him in the following words:* "Am schönsten liess es, wenn er anfing seine Kiefer aus beiden Seiten hervorzuschieben und zwo Reihen kleiner gelber Zähne herzuweisen, die zugleich mit dem Zahnfleisch sehr genau wie zween kleine und sehr feine gelbe Kämme anzusehen waren. Wenn er diese seinen gelben Zähne zum Vorschein brachte, so liess es fast ebenso, als wenn man einen Spiegel oder einen Schrank mit zwo halben Thieren öffnet, also dass jede Thüre auf ihre Seite fällt."

J. Müller, in 1836, severely criticises this passage without, it must be confessed, clearly understanding it, and asserts that it is "ganz unrichtig." His reasons are negatived, partly by erroneous anatomical observation, and partly by his failure to realise that the "tongue" and mucosa are one, and therefore must both move together. In 1873 Gunner's observations were confirmed by W. Müller (as reported by P. Fürbringer) on living material of *Myxine*, and some were killed in spirit with the dental plates everted. According to W. Müller, the action is very rapid and powerful, and is accompanied by a peculiar noise. In 1874–5 P. Fürbringer (*op. cit.*), working with W. Müller's material, published two figures of the everted dental apparatus, and gave

* See the German translation from the Danish, *Drontheim Ges. Schrift.*, ii. p. 230, 1765.

a description of the protractor muscles, which is noticed elsewhere. In 1894 AYERS * extended the observation to *Bdellostoma*, and gives two figures of this genus, showing the teeth out, but no description of the protractor muscles. Finally GOODE and BEAN † in 1895 figure, but do not mention, this phenomenon in *Myxine australis*.

The function of the two protractor muscles has, as before stated, been already discussed in some detail both by J. MÜLLER and P. FÜRBRINGER, but their results are unsatisfactory for two reasons: (1) they failed to elucidate the anatomy of the superficial protractor muscle (copulo-glossus superficialis); (2) they did not realise that a dental apparatus derived from and attached to the mucosa cannot move without carrying the mucous membrane with it, *i.e.* the teeth cannot be everted without the mucosa of the floor of the mouth being also evaginated. This oversight of the latter point is evidently due to the fact that they worked too much with dissected specimens. If a vertical longitudinal incision be made through the roof of the head and the two halves pinned out on each side so as to expose the mouth cavity, it is seen that when the dental apparatus is at rest (*i.e.* withdrawn) there is an area of puckered mucous membrane immediately behind it, whilst the mucosa in front of it is more or less tense. Now, if a similar section be made with the dental plates everted, it is seen that the mucosa on the floor of the mouth is on the stretch, whilst externally and immediately behind the (now) ventral margin of the ventral plates there is an area of evaginated and folded mucous membrane. It therefore follows that immediately behind the "tongue" there is a special fold of loose mucosa to admit of the forward movement of the teeth, and also that there is probably some muscular apparatus for evaginating the mucosa itself in front of the teeth.

The function of the deep protractor (copulo-glossus profundus) is quite simple. It draws the "tongue" straight forwards in the mid-ventral line, but we may deduce from its attachment to what is a *ventral* skeleton that it would probably require assistance before it could topple the dental apparatus over the ventral margin of the mouth, and so on to the exterior,—*i.e.* it is adapted to produce motion in a horizontal, but not in a vertical plane. This assistance is admirably provided for by the superficial protractor, which first of all evaginates the anterior ventral mucosa (thus not only paving the way, but indirectly reinforcing the pull of the deep protractor), and finally, when the "tongue" has arrived at the anterior extremity of the mouth, exercises a sharp ventral *erecting* pull (by its *dorsal* attachment) *on the teeth themselves*, in this way supplying the jerk necessary to tumble the whole apparatus downwards out of the mouth. P. FÜRBRINGER states that the tether of the hyo-copulo-glossus assists in this final act, as described under that muscle. The two protractor muscles, therefore, though playing somewhat different parts, perform one function between them, instead of both acting in much the same way, as assumed by J. MÜLLER and P. FÜRRBINGER.

* *Biological Lectures at Wood's Holl*, ii. pp. 136–7, 141–2, 1893–4.
† "Oceanic Ichthyology," *Atlas*, pl. i. fig. 2.

The "Club-Shaped Muscle."

This large muscle mass, by far the most striking feature in the myology of the Myxinoids, and the development of which is by some believed to be the cause of the suppression of the anterior gills and the displacement of the functional gills, is composed of three discrete muscles, which are, however, enclosed within a tough external fascia to form the so-called "club-shaped muscle," occupying a ventro-longitudinal position, with the handle projecting straight forwards. The principal attachments of the complex are in front, where it is connected with the posterior segment of the basal plate and with the dental apparatus. It has also two slight attachments to the lateral head of the copulo-glossus profundus and the copulo-quadratus superficialis. Dorsally it is slung to the parietal muscle by the second and third divisions of the constrictor pharyngis, whilst behind it may receive the first loop of the constrictor branchiarum et cardiæ, and also a slight bundle from the ventral longitudinal tract of the same muscle, as shown in fig. 3. Posteriorly, the first pair of gill sacks overlap the club-shaped muscle dorso-laterally.

The whole mass, together with the posterior segment of the basal plate and the dental apparatus, may be easily removed from the body and studied in detail. Portions of all three muscles constituting it may then be seen without further dissection.

18. *M. copulo-copularis.* (Figs. 2, 3, *cp. c.*)

J. Müller, *Hohle äussere Muskel der Zunge* (p. 254).
„ *Muskulöse Capsel* [*Scheide*] *des Längsmuskels der Zunge* (p. 315).
Ayers and Jackson, *M. constrictor musculi mandibuli* (p. 205).

A distinctly paired (as observed by Schneider) and very powerful transverse constrictor muscle, with an extreme length of 38 mm., width 11 mm., and depth 7 mm., in a 35 cm. Hag. It is pointed in front and obliquely truncated behind, and the longitudinalis linguæ projects behind its posterior border. Its dorsal surface is flat and its ventral surface convex. The anterior extremities of the muscle are very narrow, and are situated immediately between the dorsal margins of the limbs of the U-shaped posterior segment of the basal plate so as to complete the channel dorsally. They terminate slightly in front of the greatest depth of the cartilage, *i.e.* just anterior to the commencement of the taper at the posterior end of the anterior fourth. The muscle, however, soon begins to increase both in width and depth—as regards the latter, the increase corresponding to the diminution or dorsal taper of the posterior segment of the basal plate, until the fibres appear to meet behind the point of the cartilage at the mid-ventral line. In other words, the pointed extremity of the cartilage *apparently* interrupts the course of the fibres at the mid-ventral region. In

front, the fibres of the muscle are attached to the free margin and the dorso-internal surface of each limb of the posterior segment, but behind, as the latter loses its U-shape and becomes flattened dorsally, and the muscle extends dorsally and laterally to it, the attachment spreads over the whole dorsal surface of the cartilage, and the two halves of the muscle therefore meet at the mid-dorsal line of the posterior segment of the basal plate. Hence we cannot say that the cartilage is everywhere interpolated in the course of the muscle fibres, and thus represents a modified portion of the muscle, since, anatomically, there is nothing to show that the muscle was ever more extensive than it is now. However, the connection between the cartilage and the muscle is of so intimate a nature that the former has been stated by AYERS and JACKSON to represent the tendon of the latter which has become converted into a simple form of cartilage, and which was originally inserted into the posterior extremity of the middle segment of the basal plate. To this view I assented in my first Part (p. 756), but on further consideration it seems impossible that the muscle in question can be the copulo-copularis, since this is a *transverse constrictor* muscle, and as such has no tendon at all. SCHAFFER, in two earlier papers, regarded the posterior segment as a sesamoidal formation in the tendon of the "M. retractor linguæ," but even if this is not a slip for copulo-copularis it cannot be correct. We must, however, here note that the posterior region of the copulo-copularis is U-shaped in transverse section, and in this respect is similar to the cartilage, but the conversion of the anterior region of the muscle into the cartilage postulates a series of changes of which there is at present no evidence whatever.

Dorsally, the two halves of the copulo-copularis are separated by a median ligamentous linea, which in front is a specialisation of the stout fibrous roof of the posterior segment of the basal plate. This linea is at first narrow, but gradually widens as it passes backwards. At the middle of the muscle the two halves begin to diverge dorsally, and this divergence continues up to the posterior extremity, where the two halves were 6 mm. apart in the above specimen, and the longitudinalis linguæ was plainly visible between them. They are, however, connected by a tough sheet of transparent fascia, which in front is directly continuous with the opaque linea above. The lateral margin of the linea and of the sheet of fascia throughout the greater part of the thickest portion of the muscle sends down on each side a vertical longitudinal fibrous sheet, which extends in places through the thickness of the upper half of the muscle, forming an intra-muscular fascia inclining towards the mid-dorsal line. Fibres are attached to both sides of this sheet, so that in transverse section it has a bi-pinnate appearance.

Ventrally there is also a median linea, which is wide in front before the two halves of the muscle meet at the middle line, but behind it is very narrow from side to side, although traversing the thickness of the muscle vertically so as to completely separate the two halves below. At the posterior extremity the inferior chondroidal bar plunges into the muscle and gives origin to a few of the fibres. In *Bdellostoma*, J. MÜLLER

says that *none* of the fibres of the copulo-copularis arise from the inferior chondroidal bar, but in *Myxine* I have seen it in all my dissections and sections. There is, however, no connection with the superior chondroidal bar.

It is quite clear from a merely superficial examination that all the fibres of the copulo-copularis, whilst they always pass transversely at right angles to its long axis (except at the posterior extremity), do not form complete half hoops. This is especially well seen in the longitudinal dorso-lateral spindle-shaped projection which extends from one extremity of the muscle to the other. This projection consists of short transverse fibres, the most superficial of which arose from the external fascia 3 mm. from the mid-dorsal line in a 35 cm. Hag, and after a short maximum transverse course of 4 mm. were inserted also into the external fascia (cp. fig. 3). Hence the copulo-copularis is thickest at the region of this projection. In fact by far the greater portion of the surface of the external fascia of the muscle is utilised for the origin and insertion of its fibres, so that in a surface view one sees, apart from the tract above, only the ends of muscle fibres, and not their course, as shown in the above figure. In other words, the muscle fibres become gradually longer as they pass from without inwards. Again, at the anterior region, where the muscle is flattened dorso-ventrally, the fibres are all nearly vertical, passing from the dorsal to the ventral fascia of the muscle, with, however, a slight incline towards the mid-dorsal line. Hence the most internal, and not the most external, fibres are the longest, because they traverse a greater vertical thickness of the muscle, and they, only, pass from the mid-dorsal to the mid-ventral linea. The external fascia may be described as providing the origin and insertion for the greater part of the fibres which course in a slight but internally increasing curve from the dorsal to the ventral fascial regions. At the posterior extremity the fibres do not follow a strictly transverse course, but pass obliquely downwards and *backwards*, and hence the oblique posterior margin of the muscle is formed by the *ends* of these muscle fibres.

By making a median dorsal incision through the posterior fascia and the anterior linea the two halves of the muscle may be pinned out. It is then seen that the muscle forms a hollow tube, complete in front, where it is continuous with the channel of the posterior segment of the basal plate, but only completed behind by the dorsal fascia mentioned above. In this canal is situated the M. longitudinalis linguæ behind, and in front its tendon. The cavity is wider behind, where it has to accommodate the belly of the longitudinalis linguæ, but gradually narrows in front, where it only has to lodge the tendon. Hence the copulo-copularis is thickest where the channel is narrowest, and it is important to remember this when considering the function of this muscle. Assuming, in the dead state, that the muscle is in contraction, the size of its cavity is subject to enlargement. The median ventral linea is very obvious internally, and the most internal fibres, *i.e.* those lining the cavity, are seen to be the longest and the most curved, since they arise and are inserted into the most median positions, and hence have to describe a curve in order to enclose a central cavity.

19. *M. longitudinalis linguæ.* (Figs. 2, 3, 6, *l. l.* (Part I.), *l. lg.*)

J. MÜLLER, *Innere Längenmuskel der Zunge* (p. 256).
AYERS and JACKSON, *M. retractor mandibuli* (p. 204).

This may also be regarded as a paired muscle. Posteriorly it projects behind the truncated extremity of the copulo-copularis, and thus far is visible without dissection, but the greater part of the belly is concealed in the cavity of the latter muscle. When its tendon leaves this cavity in front it traverses the channel of the posterior segment of the basal plate, which is roofed over and converted into a tube by tough fibrous tissue, but in front of this again the tendon works only in a groove open dorsally, the floor of which is formed by the two anterior segments of the basal plate and the sides by the paired rails described on p. 773 of my first Part. This groove gradually dies away in front, and is lost a short distance behind the anterior margin of the anterior segment of the basal plate. It serves as a guide to the dental skeleton when the latter is in the mouth, and transmits the tendon of the present muscle when the "tongue" is everted.

By making a median dorsal longitudinal incision through the copulo-copularis and the roof of the channel of the posterior segment of the basal plate, the longitudinalis linguæ, together with the attached perpendicularis, may be removed intact, along with the dental apparatus, and examined carefully under a dissecting microscope. It is then seen to arise as follows:—(*a*) the dorso-external fibres arise from the lateral under-surface and lateral margin of the superior chondroidal bar, *i.e.* from practically the whole ventral surface of this cartilage not occupied by the perpendicularis. It also arises, according to P. FÜRBRINGER, from the stout fascia in which this cartilage lies (= broadened out dorsal linea of the copulo-copularis), but I cannot confirm this either from dissections or sections; (*b*) the lateral and ventral fibres, comprising the greater part of the muscle, arise, like a bipinnate muscle, from a median vertical ligamentous (or pseudo-cartilaginous —cp. especially p. 780 of my first Part) partition situated in the longitudinal plane at the posterior end of the muscle; (*c*) a small posterior bundle, forming the most ventral fibres of the muscle, arises from the dorsal surface of the posterior tip of the inferior chondroidal bar. (Cp. figs. 2 and 3. On p. 779 of my first Part it is erroneously stated that the longitudinalis linguæ has no connection with the inferior chondroidal bar.) The above very curious reinforcement (*c*), which seems so small and useless, is paired, each half of the muscle receiving a bundle. In the sections the left bundle was much larger than the right. The latter first of all sharply dips down in the median plane between the fibres of the perpendicularis to reach the inferior bar, and the left one does the same immediately behind it. All the fibres of these two bundles, however, do not arise from the bar, but some of them from the vertical sheet described above.

From their origin the fibres of the longitudinalis linguæ pass outwards and forwards in a curve in order to embrace the lateral surfaces of the perpendicularis. They soon pass straight forwards (apart from their convergence), and in front of the perpendicularis the muscles of the two sides are closely opposed by their median flat surfaces, but do

not fuse. The entire mass is oval in transverse section. Dorsally, the division between the two muscles can be traced almost to the tendon, but ventrally the anterior third shows at the middle line a ligamentous cord, which is apparently continuous with the tendon of the muscle in front. The fibres converge gradually both laterally and vertically as they pass forwards, so that the whole muscle resembles a tapering pointer. Its depth behind in a 34 cm. Hag was 7 mm. and its width 9 mm., whilst the entire length of the muscle belly was 35 mm. The anterior half of the muscle, *consisting of larger and less concentrated fibres*, is spindle-shaped, and its pointed posterior end is buried in the anterior end of the posterior half (cp. the detailed description of the tendon below). The fibres of the latter half, therefore, are inserted into the outer tendinous surface of the buried end of the anterior half. Hence there is a fresh origin of (histologically different) fibres to form the anterior half of the muscle.

The belly of the longitudinalis linguæ passes into a strong laterally-compressed tendon, with a maximum depth in the above specimen of nearly 2 mm. This tendon courses straight forwards to the dental apparatus, slightly increasing in bulk as it proceeds, and having a length of 15 mm., to be inserted (in one dissection) as follows :— (*a*) examined dorsally, the tendon split so as to give off a pair of largish lateral bundles. These rapidly diverged, and were inserted mostly into the *lateral* portion of the posterior arch of the dental plate (Part I., fig. 9). Some of the superficial fibres, however, crossed over the posterior arch, traversed the space between the two arches, and were inserted into the anterior arch of the dental plate. These have been dissected away in the above figure. P. FÜRBRINGER states that *all* the fibres are inserted into the anterior arch (cp. the description of the tendon from sections below); (*b*) examined ventrally, the greater portion of the tendon formed a powerful median bundle, which passed forwards and expanded somewhat to be inserted into the *median* portion of the posterior arch of the dental plate (Part I., fig. 7). Here again the most superficial fibres crossed the posterior arch and the space in front, and were also inserted into the anterior arch, becoming there continuous with the superficial fibres of the copulo-glossus profundus, as described under that muscle (not shown in fig. 7 above).

I now describe the formation and insertion of the tendon as seen in my large series of sections, which disclose a very interesting state of affairs (cp. particularly the series of transverse sections given in fig. 6).

The tendon of the longitudinalis linguæ really commences far back in the interior of each division of the muscle at about section 1885 (the muscle itself extends back to 2287) as a vertical slip, with an inclination towards the middle line (1750, *a*). As we pass forwards these slips increase in length, and bend more towards the middle line, whilst a second more ventral pair are added (1570, *b*). The next stage is the fusion of both pairs of slips, the first pair to form a large half loop the ventral extremities of which now appear on the surface of the muscle, and the second pair to form a median vertical partition, with at first a ventral fork to indicate its paired origin (1498). The hoop encloses the larger and more spongy muscle fibres forming the

anterior half of the belly referred to above. The median division between the two muscles is somewhat early lost in the sections, but I have assumed that the partition *b* will represent the boundary between the two sides. We now find that the hoop extends vertically, and finally fuses at the mid-ventral line to form a complete circle, which encloses all the muscle fibres present (= the anterior half of the belly) and also the second division of the ligament, *b*. All the fibres outside the hoop in 1498 (= the posterior half of the belly) have now died away. At the same time the second or internal portion of the ligament loses its ventral fork, and with it all traces of its paired origin (1260). The outer or circular portion of the ligament next becomes smaller and more circular, and the fibres tend to concentrate below, leaving the dorsal half non-tendinous (cp. 720). Further, the internal tendon loses its vertical sheet-like character and becomes spherical (870). In the next stage (720) we find the dorsal half of the outer circle (a') entirely non-tendinous, all the tendon fibres being concentrated below in a large *median ventral tendon* (a), the centre of which is invaded by a weak, soft, pseudo-cartilage. The remainder of the circle (a') is membranous and lodges the nerves at the mid-dorsal line, whilst the internal tendon has now split up again to form the *dorsal paired tendon* ($1b$, $2b$) separated by a median vertical membranous partition (a''), and with their external membranous sheaths connected below with the dorsal non-tendinous portion (a''') of the ventral tendon. Now the dorsal membranous portion of the circle (a'), then the median partition (a''), and finally the dorsal fibrous portion of the ventral tendon (a'''), fuse with the median ventral wall of the gut. Whilst this is happening (625), the dorsal tendons, having diverged, split vertically into two ($1b'$, $1b''$, $2b'$, $2b''$). The inner of these ($1b''$, $2b''$) are inserted into the ventro-lateral wall of the gut, and *not* into the dental skeleton. The outer ones ($1b'$, $2b'$) cross the posterior arch of the dental plate internally, and become continuous with the tissue bridging the large gap between the anterior and posterior arches of the dental plate at the posterior base of the inner row of teeth. In these two ways the tendon of the longitudinalis linguæ becomes intimately related to the gut and the dental mucosa, so that its pull will act on these structures as well as on the dental skeleton.

The median ventral tendon (a) fuses with the median portion of the posterior arch of the dental plate, and is in fact partly morphologically continuous with it, since a large portion of the tendon becomes converted into soft pseudo-cartilage containing nests of soft cartilage, and thus passes without any hard-and-fast break into the soft cartilage of the posterior arch. Many of the fibres, however, do not terminate in this way, but cross on either side of the posterior arch, to pass over into the stout membrane connecting the two arches of the dental plate, and also partly into the tendon of the copulo-glossus profundus, as described under that muscle. According to SCHAFFER'S latest paper, the whole of the above membrane is invaded by soft pseudo-cartilage, but it is only partly so in my preparations.

The extension of the dental apparatus is effected by two muscles, the superficial

protractor acting on the mucosa and teeth, and the deep protractor acting on the dental skeleton itself. Although the withdrawal of the apparatus is obviously a simple process, and is in point of fact effected by one muscle, the longitudinalis linguæ, nevertheless the division of the tendon of this muscle is of such a nature as to roughly antagonise the pull of the two protractors. The median ventral tendon corresponds to the deep protractor, and acts directly on the dental skeleton. The paired dorsal tendons correspond to the superficial protractors, and act rather on the mucosa posterior to the teeth. The protractors and retractor may, of course, represent one muscle, with the dental skeleton as a sesamoidal deposit. Cp. the function of the protractor muscles.

20. *M. perpendicularis.* (Figs. 2, 3, *pp.*)

J. Müller, *Innere senkrechte Muskel der Zunge* (p. 257). *Senkrechter Muskel des Zungenmuskelapparates* (p. 331).

This is an unpaired median vertical muscle, and courses between and separates the posterior ends of the two longitudinalis linguæ muscles like a rod pushed through a loop. It is a short but powerful muscle, wide antero-posteriorly, and slightly compressed from side to side. In transverse section it is somewhat pear-shaped, with the narrow end anterior. In a 34 cm. Hag it had a maximum width of 5 mm. and height of 7 mm. It arises from the dorsal and lateral surfaces of the posterior two-thirds of the inferior chondroidal bar, and its parallel fibres pass upwards and somewhat forwards to be inserted into the middle ventral surface of the superior chondroidal bar, *i.e.* except for a short region anteriorly, and the lateral zones occupied by the dorsal fibres of the longitudinalis linguæ.

The function of the three muscles constituting the retractor apparatus of the "tongue" is a subject of as considerable interest as the apparatus itself is unique. The longitudinalis linguæ has been dealt with already, so that it is here only a question of the other two. According to J. Müller, the perpendicularis, by compressing flat the posterior end of the muscle mass, fixes this end of the longitudinal muscle, whilst the latter, by drawing the dental apparatus sharply back, enables the ventral teeth to scratch and file away the prey already fixed by the palatal tooth. The copulo-copularis is stated to fix the longitudinal muscle in the retracted condition; but Müller is undecided whether the contraction of the constrictor muscle might not also squeeze the longitudinal muscle out, and thus assist in everting the dental apparatus. On the other hand, P. Fürbringer regards the constrictor muscle as a powerful supporter of the protractors of the "tongue," but agrees that the vertical muscle fixes the longitudinal muscle at its posterior end. To quote his own words, he says (p. 24)—"Durch die Contraction des Hohlmuskels wird zunächst der Hohlraum derselben erheblich verengt; dieser Volumenreduction muss natürlich auch der Längs-

muskel folgen, dessen Verkleinerung im Querschnitt zur Verlängerung des Muskels d.h. (da sein hinteres Ende fixirt ist) zu einer Vorwärtsbewegung der Sehne in dem engen vordern Abschnitt des Canals und Halbcanals führen muss." Against this view must be arranged two facts : (1) the longitudinal muscle at the region of its greatest bulk *projects beyond the posterior extremity of the constrictor muscle* ; (2) as the longitudinal muscle decreases in bulk, the constrictor correspondingly increases in strength. These facts, to my mind, entirely negative FÜRBRINGER'S view, and rob of any point his criticism of MÜLLER's explanation, which he appears to me to misunderstand. It is also difficult to see how the action of the vertical muscle can replace the constrictor posteriorly so as to have a similar pushing effect on the longitudinal muscle. I, however, agree with FÜRBRINGER that a movement of the ventral margin of the mouth itself at the critical moment would assist in toppling the dental apparatus out of or into the mouth, as the case might be.

I took an opportunity of demonstrating this very curious mechanism to Professor SHERRINGTON, who suggested an explanation which appears to me to meet the facts of the case, and to represent also what J. MÜLLER was driving at. We may first of all safely conclude that the tonic condition of the dental apparatus is one of rest, *i.e.* that the longitudinal muscle is at most times in a state of contraction. This muscle will correspond to a rapid or quick muscle which executes a movement that may be rapidly repeated (withdraws the dental apparatus). The constrictor will thus correspond to a sluggish or tonus muscle which preserves an attitude (maintains the tonic condition of retraction). The constrictor, therefore, neither reinforces the pull of the longitudinal muscle nor that of the protractors, but, on the dental apparatus reverting to its tonic condition after being in action, maintains that condition, whilst the longitudinal muscle becomes passive again. Consequently, when the dental apparatus is active, it is the constrictor muscle that is passive (and, of course, relaxed). Similarly, the perpendicular or vertical muscle is a tonus muscle, fixing the posterior end of the longitudinal muscles, which project beyond the sphere of the constrictor muscle. Against this view, however, I ought to state that the fibres of the longitudinal and constrictor muscles are large, of the same size, aplasmic, not richly vascular, and very distinctly cross-striated. Hence the morphological distinction we should expect to find has no existence, and both are *morphologically* tonus muscles ; but as all the muscles of *Myxine* except the velo-quadratus, velo-spinalis, cordis caudalis, and the mixed parietals are of this type, this point perhaps loses in importance. I have, however, seen in at least one other muscle (the copulo-tentaculo-coronarius) a few scattered plasmic fibres.

21. *M. copulo-palatinus.* (Figs. 3, 9, *c. pl.*)

J. MÜLLER, *Heber des Zungenbeins* (p. 249). *Zungenbeinheber* (p. 324).

In the case of a muscle such as this, the terms " origin " and " insertion " can only have a purely arbitrary meaning, since neither termination of the muscle is a fixed point.

A fairly powerful flat muscle, which arises from the ventral or convex margin of the cornual cartilage at the bend immediately in front of the origin of the hyo-copulo-palatinus, and opposite the insertion of the palato-ethmoidalis profundus. It is covered externally partly by the first two myotomes behind and partly by the superficial and deep copulo-glossus muscles below. In the sections the cornual cartilage appears in about 140 sections, of which 60 are in front of the origin of the copulo-palatinus and 20 behind it.

The fibres of the copulo-palatinus course downwards and backwards, somewhat diverging, bend over the external bar of the anterior segment of the basal plate external to the first head of the copulo-tentaculo-coronarius on to the internal bar of the same, into the sheath of the ventral surface of which it is inserted near the middle line from its extreme anterior margin up to the commencement of the median fenestra. In the sections it is continued slightly behind and at the side of the fenestra, and, further, it is seen that the two muscles are joined up below the internal bar by a median ligament, and that the latter is attached, and not very securely, at about the middle line of the internal bar.

In front of the anterior margin of the internal bar of the basal plate the external fascia of the copulo-palatinus is observed in the sections to fuse with the longitudinal sheet of fascia stated by J. Müller and P. Fürbringer to be the tendon of the hyo-copulo-glossus (*q.v.*). It presents the appearance in the sections as if some of the fibres of the present muscle were inserted into this sheet also.

As pointed out by P. Fürbringer, the function of this muscle will depend upon which end of it acts as the fixed point. As far as the copulo-palatinus is concerned the cornual cartilage can be fixed by the palato-ethmoidalis profundus, in which case the muscle would tend to approximate the external bars of the anterior segment of the basal plate, and thus compress the mouth cavity laterally, and approximate the two halves of the dental apparatus dorsally. When, however, the cornual cartilage is not fixed, the contraction of the copulo-palatinus would of course depress it. J. Müller states that the muscle elevates the basal plate and draws it somewhat forwards, in that way shutting the mouth. He also recognises that it may also compress the mouth cavity laterally.

22. *M. hyo-copulo-palatinus.* (Fig. 3, *h. c. p.*)

J. Müller, [*Erster*] *Vorwärtszieher des Zungenbeins* (p. 248). *Vorderer Vorzieher des Zungenbeins* (p. 322). *Erster Vorzieher des Zungenbeins* (p. 324).

A wide, powerful muscle, covered externally by about the first three myotomes, and its dorsal border situated immediately below the ventral border of the tentacularis posterior in front.

The hyo-copulo-palatinus arose, in a dissection, mostly from the external fascia of the copulo-quadratus profundus at about the middle and upper portions of its course. A few fibres, however, arose in front from about the middle of the cornual cartilage

immediately behind the posterior border of the insertion of the copulo-palatinus into the same. In the sections, the muscle arose almost exclusively from the fascia of the internal angle of the ventral border of the tentacularis posterior. Even when its dorsal border dips down so as to lose direct connection with the tentacularis posterior, it still remains attached to it for some little distance by a ligamentous sheet. Again, in the sections the dorso-anterior angle of the muscle does not reach the cornual cartilage, but it is connected with it by a short strong bundle of fibrous tissue, just where the cartilage fuses with the palatine commissure. No fibres arose, or could arise, from the palatine bar, as the hyo-copulo-palatinus is widely separated from it at its origin by the copulo-quadratus profundus and the palato-coronarius.

J. MÜLLER states that the present muscle arises from the most anterior part of the palatine bar in *Bdellostoma*, whilst in *Myxine* P. FÜRBRINGER asserts that it arises from the posterior end of the cornual cartilage, and even from the palatine bar, and he mentions finding in one specimen a bundle arising from the fascia of the copulo-quadratus profundus. His fig. 5 agrees largely with what I have found.

The fibres of the hyo-copulo-palatinus course downwards and backwards, somewhat diverging, to be inserted as follows :—(*a*) a few fibres are inserted into the ventro-external surface of the external bar of the anterior segment of the basal plate immediately below the insertion of the copulo-quadratus profundus. In the sections the muscle was well attached by fibrous tissue to about the ventral or inner half of the posterior sixth of the external bar; (*b*) two-thirds of the muscle are inserted into the ventro-external face of the middle segment of the basal plate, in front near the outer margin, then passing inwards about half way towards the middle line, and finally rising again behind so as to be situated over or external to the insertion of the rectus muscle and to reach the root of the first branchial arch; (*c*) a large posterior bundle, representing the remaining third, and which may be more or less distinct from the remainder of the muscle, as shown in fig. 3, courses backwards and slightly downwards, slips under the antero-ventral margin of the cranio-hyoideus, and in a 35 cm. Hag was inserted into the *anterior* surface of the most ventral 3 mm. of the first branchial arch between the insertion of the cranio-hyoideus and the origin of the hyo-copulo-glossus, *i.e.* external to the origin of the latter muscle (*q.v.*). In the sections this part of the insertion is so confused with the origin of the hyo-copulo-glossus that I could not satisfactorily separate them.

The function of the hyo-copulo-palatinus is principally to draw the basal plate (and hence the ventral margin of the mouth) upwards and forwards.

23. *M. copulo-quadratus superficialis.* (Fig. 3, *c. q. s.*)

J. MÜLLER, *Hinterer Vorwärtszieher des Zungenbeins* (p. 248).
„ *Hinterer Vorzieher des Zungenbeins* (p 323).
„ *Zweiter Vorzieher des Zungenbeins* (p. 324).

P. FÜRBRINGER states that this muscle may in exceptional cases be either extremely

reduced or even absent, but I have never encountered this variation either in my dissections or sections.

A fairly powerful and apparently club-shaped muscle, with the handle directed backwards, and the whole covered externally by the parietalis. The shape is due to the fact that whilst the dorsal half of the fibres passes straight back to its insertion, the ventral half bends inwards and slightly upwards at a right angle between the copulo-glossus superficialis ventrally and the constrictor pharyngis I. dorsally to reach its insertion, which is thus internal to the dorsal half.

The anterior extremity of the muscle arises—(*a*) from the fascia of the dorso-posterior border of the hyo-copulo-palatinus; (*b*) from the fascia of the dorso-posterior portion of the copulo-quadratus profundus; (*c*) from the fascia connecting the superior and inferior processes of the pterygo-quadrate (in the sections); and (*d*) largely from the inferior process of the pterygo-quadrate itself. From its origin, the muscle passes backwards and somewhat downwards, crosses transversely the cranio-hyoideus and constrictor pharyngis I., and finally bends inwards over the copulo-glossus superficialis in front, and over the lateral head of the copulo-glossus profundus for a short distance behind, to be inserted as follows: the dorsal half of the fibres is inserted partly into the ventro-lateral fascia of the anterior extremity of the copulo-copularis, but also largely into the dorsal margin of the posterior segment of the basal plate from the beginning of the taper *backwards*, and dorsal to the origin of the copulo-glossus superficialis, which for a time may even exclude it from the basal plate. For a short distance posteriorly (in the sections) it was wedged in between the lateral head of the copulo-glossus profundus and the copulo-copularis; the ventral half of the fibres is inserted into the dorsal margin of the posterior segment of the basal plate in front of the above, *i.e.* from the beginning of the taper *forwards*. The whole origin in a 35 cm. Hag extended over 7 mm. of the posterior segment. It must be remembered that the latter is here U-shaped, and that, therefore, the dorsal margin on each side is a free and somewhat thin border.

According to J. Müller in *Bdellostoma*, the copulo-quadratus superficialis is "inserted" into the margin of the palatine bar where this passes over into the pharyngeal basket. As P. Fürbringer points out, this "insertion" is carried much further forwards than in *Myxine*; and as the basal plate is the movable point, it is as well to call *that* extremity of the muscle the insertion.

The function of this muscle seems to be the same as that of the hyo-copulo-palatinus.

24. *M. copulo-quadratus profundus.* (Fig. 3, *c. q. p.*)

J. Müller, *Zurückzieher des Zungenbeins* (p. 249).

A very wide, powerful muscle, situated mostly under the hyo-copulo-palatinus, and in part just external to the mucosa of the mouth. It has an irregular or ragged dorsal

origin as follows:—(*a*) from the skeletogenous layer of the lateral wall of the membranous cranium just external to the massed cranial ganglia (which lie in a space produced by the separation of the two layers constituting the cranial wall), commencing at its anterior end immediately behind the eye, and passing backwards in a descending curve on to the root of the superior process of the pterygo-quadrate. Some of the deeper fibres in front arose in a dissection (but not in the sections) from the anterior process of the pterygo-quadrate. This part of the origin was not found by P. FÜRBRINGER. On the right side, in my large series of sections, the origin extended further forwards so as just to cover and obscure the eye—here arising from the optic capsule; (*b*) the origin now extends vertically downwards in a curve over the external surface of the central portion of the pterygo-quadrate on to the root of the inferior process of the same, from the external ventral surface of the entire length of which latter it also arises; (*c*) the origin is finally continued backwards across the hyoid (immediately above the ventral zone of soft cartilage in front), and then rises slightly so as to pass over the posterior flat process of the hyoid, here lying internal to the cranio-hyoideus. A few fibres arose from the root of the inferior lateral cartilage, as stated by P. FÜRBRINGER. In the large series of sections the origin did not rise on to the posterior flat process of the hyoid, but passed straight on to the dorso-external surface of the root of the inferior lateral cartilage, and terminated directly the latter was separated off from the hyoid.

The fibres of the copulo-quadratus profundus course downwards and forwards in large fasciculi, only slightly converging, and are inserted into the lateral (dorsal) margin of the external bar of the anterior segment of the basal plate throughout its entire extent. A few fibres were inserted into the pad of soft pseudo-cartilage at the anterior end of the external bar, and a few also into the lateral margin of the anterior end of the middle segment. P. FÜRBRINGER states that it is inserted into the anterior third of the latter.

In the sections, the insertion into the external bar was carried anteriorly to immediately behind the fusion of the lateral labial with the external bar. In order to reach the latter, these anterior fibres had to pass over the external surface of the posterior extremity of the pad of soft pseudo-cartilage (cp. Part I., fig. 1), but I think few, if any, fibres were inserted into it. Posteriorly, in the sections, the insertion was carried over the pad of soft pseudo-cartilage between the external bar and the middle segment of the basal plate on to the lateral margin of the anterior fourth of the latter.

The function of the copulo-quadratus profundus is to draw the basal plate (and hence the ventral margin of the mouth) upwards and backwards, and in this way to widen the mouth cavity laterally.

25. *M. velo-quadratus.* (Figs. 3, 7*d*, 11, 12, *v. q.*, *v. q'.*, *v. q''.*)

J. Müller, *Anzieher des Schlundsegels* (p. 260).

I describe this muscle as dissected from the ventral surface. It is an extensive and irregular muscle, with its fibres arranged into coarse fasciculi, and the fasciculi grouped into three perfectly distinct divisions (both in dissections and in the sections), which might almost be described as three separate muscles.

Ventral Division (*v. q.*).—Arose in one dissection—(*a*) from the lateral margin of the central expanded portion of the hypophysial plate; (*b*) from the tough tissue between the latter plate and the pterygo-quadrate; (*c*) from the internal surface of the pterygo-quadrate at, and in the immediate neighbourhood of, the zone of soft cartilage between the palatine bar and the pterygo-quadrate. In the sections a small portion of the fibres arose from the stout membrane connecting the hypophysial plate with the anterior extremity of the soft cartilage portion of the trabecula. The origin then passed on to the lateral margin of the above plate immediately before this fused with the rod from the nasal capsule. The receipt of the latter adds to the width of the plate, so that the ventral division, since it continues its origin straight backwards, no longer arises from the lateral edge of the plate, but from the ventral or external surface of it, not quite half way down. When, however, the trabecular connection is given off from the plate,* the muscle again arises from its lateral margin, until it is displaced from it by the anterior extremity of the origin of the dorsal division. There were no signs of any origin from the pterygo-quadrate.

The fibres of the ventral division pass backwards and outwards, and finally converge to be inserted into the ventro-external portion of the anterior or free surface of the expanded head of the external lateral velar bar. The ventral division almost entirely covers the middle division ventrally, but the dorsal division appears behind at its median margin.

Middle Division (*v. q'.*).—Arose in the same dissection—(*a*) apparently from the cranium slightly behind the level of the origin of the ventral division; (*b*) from the ventro-internal surface of the anterior end of the trabecula. In the sections it arose (*a*) from the ventral surface of the anterior soft cartilage portion of the trabecula; (*b*) from the same surface of the naso-trabecular cartilaginous commissure at and in the neighbourhood of its fusion with the hypophysial plate; (*c*) from the tough membrane between the latter plate and the trabecula; (*d*) from the ventro-internal surface of the zone of soft cartilage between the pterygo-quadrate and the palatine bar.

The fibres of the middle division pass backwards and outwards, and converge slightly to be inserted into a knob of *soft* cartilage at the dorso-external margin of

* The correct view to take of these cartilaginous fusions is that they represent a connection between the olfactory capsule *and the trabecula* which fuses with the hypophysial plate *on the way*. This is also suggested by Neumayer's figure and by my own sections.

the anterior surface of the expanded head of the external lateral velar bar. This is the division of the velo-quadratus one sees in a lateral external view in the anterior half of the third fenestra of the skull (figs. 3, 11, *v. q'.*).

Dorsal Division (*v. q''.*).—The most dorsal and the largest division of the three. Partly covered ventrally by the middle division. It arose in the same dissection:—(*a*) a few fibres from the lateral margin of the central expanded portion of the hypophysial plate; (*b*) the greater part apparently from the cranium at a level slightly posterior to the origin of the middle division; (*c*) some fibres from the ventro-internal surface of the anterior half of the trabecula behind the origin of the middle division. In the sections the origin was somewhat different. No fibres arose from the cranium, but they all arose from the ventral surface and internal margin of the trabecula opposite the posterior half of the first fenestra of the skull, and also from the lateral margin and dorso-internal surface of the hypophysial plate.

The fibres of the dorsal division pass backwards and outwards almost parallel, and finally have an oblique insertion into the internal surface of the external lateral velar bar from a short distance behind the free extremity up to and slightly beyond the origin of the internal lateral velar bar. In fact, some of the fibres were inserted into the base of the latter also, although in the sections the insertion terminated immediately in front of the origin of the internal bar.

The above account differs from P. FÜRBRINGER'S in several respects, but more particularly in that this author did not find the division of the muscle into three parts. J. MÜLLER mentions two parts in *Bdellostoma*, which are stated to be antagonistic in action (anatomically quite possible in *Myxine*); but FÜRBRINGER disputes the accuracy of this statement, and insists that in *Myxine* the insertion is quite continuous.

The velo-quadratus is stated to act as the occlusor of the naso-pharyngeal opening, but the fact that it consists of small plasmic vascular fibres, similar to those of the cordis caudalis, would indicate that it is either a rapid or a rhythmic muscle. Thus the velum may well act as an apparatus which, by a pulsating motion, draws the respiratory water into the pharynx. If this is not so, it is difficult to understand how the water reaches the gills, since the intrinsic and extrinsic musculature of the gills would only expel water from the respiratory apparatus already there. On this view the velo-spinalis is, of course, also a rapid muscle.

26. *M. velo-spinalis.* (Figs. 7*e*, 12, *v. s.*)

J. MÜLLER, *Anspanner des Schlundsegels* (p. 261 and p. 317, λ).

Before describing this muscle, I may mention here a ligament found in its neighbourhood. It is of course a part of the general and diffuse ligamentous system found in *Myxine*, and has a somewhat indefinite origin from the region of the dorso-internal surface of the hyoid arch. It then passes forwards, upwards, and inwards, and is

inserted into the scooped-out hollow on the ventral surface of the head, and also into the margins of the external lateral velar bar.

Like the velo-quadratus, the velo-spinalis is a small-fibred muscle. It has a long extended origin from the ventro-lateral surface of the skeletogenous layer of the notochord, commencing just behind the posterior extremity of the parachordal cartilages, and internal to the anterior portion of the origin of the first division of the constrictor pharyngis. In the sections the postero-ventral border of the origin was connected by a fibrous cord with the dorso-external margin of the anterior extremity of the anterior connecting process of the suprapharyngeal skeleton (cp. Part I., fig. 16, *sp. sk'.*, about section 780). J. MÜLLER, in the description of his plates (p. 317), also mentions this connection, and in fact there describes the muscle as passing only between the two portions of the velar skeleton, and not as arising from the chorda. This, however, is figured and also described in the text. P. FÜRBRINGER describes the chordal end of the muscle as its insertion; but as this end is obviously the fixed point, this is not permissible.

From its origin the velo-spinalis, with fibres converging, passes at first downwards, and then bends sharply so as to course forwards, outwards, and downwards in a gentle curve as a small compact cylindrical muscle, lying internal to the cranio-hyoideus, and separated from the velo-quadratus by the pharyngeal diverticulum described on p. 777 of my first Part. The insertion, however, is effected immediately anterior to this diverticulum, and there the two muscles meet and are closely associated. After a course of 5 mm. in a 35 cm. Hag, the velo-spinalis was inserted into the dorso-external surface of the head of the external lateral velar bar where this appears in the third fenestra of the skull, and seems at first sight to represent the posterior continuation of the external fibres of the middle division of the velo-quadratus. In the sections it was inserted mainly into the dorso-external margin of the bar, but as it approached the extremity of the head it extended somewhat on to its external surface. Hence the velo-spinalis appears in the third fenestra of the skull immediately behind the middle division of the velo-quadratus. This portion, however, has been cleared away in figs. 3 and 11.

According to P. FÜRBRINGER, the velo-spinalis displays the velum laterally by drawing the head of the external lateral velar bar inwards, and in that way inducing a general outward rotation of the bar (but *cp.* the function of the velo-quadratus).

27. *M. cranio-hyoideus.* (Figs. 3, 11, *c. h.*)

J. MÜLLER, *Erster Constrictor des Schlundes* (pp. 260, 324).

P. FÜRBRINGER, on the score of innervation, objects to J. MÜLLER regarding this muscle as a division of the extensive constrictor pharyngis. There would, however, be a very strong resemblance between these two muscles if it were not for the fact that

the former passes internal to the superior lateral cartilage and the latter external to it. In the meantime, therefore, and in the absence of any information at first hand as to its innervation, I follow FÜRBRINGER in separating this muscle from the constrictor pharyngis.

The cranio-hyoideus is a small but an interesting and curious muscle. In one specimen dissected it arose as follows:—(*a*) a few fibres from the posterior edge of the bridge of soft cartilage connecting the auditory capsule with the upper extremity of the hyoid arch; (*b*) most of the fibres from the ventral and posterior surfaces of the posterior end of the auditory capsule; (*c*) a few fibres from the external border of the parachordal immediately behind the auditory capsule. ALLIS* states that in *Bdellostoma* this muscle arises from the notochordal sheath immediately posterior to the auditory capsule. In my sections it arose exclusively from the auditory capsule on the right side, and on the left side partly from the capsule and partly from the fascia covering the soft cartilage of the postero-lateral extremity of the parachordal.

Just below its origin the cranio-hyoideus narrows down to pass *under* the root of the superior lateral cartilage, and emerges below it between the hyoid and first branchial arches. It at once fans out so as to occupy a part of the space between the above two arches, and now proceeds in a vertical curve downwards and slightly backwards. It crosses *externally*, and obscures, the flat posterior process of the hyoid arch, the origin of the most posterior fibres of the copulo-quadratus profundus, the insertion of the hyo-copulo-palatinus into the first branchial arch, and the inferior lateral cartilage, but passes internal to the copulo-quadratus superficialis. Hence this muscle passes through the fourth fenestra of the skull.

Below the flat posterior process of the hyoid arch the fibres of the cranio-hyoideus converge again, and in a 35 cm. Hag were inserted into the *external* surface of the most ventral 2 mm. of the first branchial arch (*i.e.* just where this fuses with the basal plate), external to the insertion of the large posterior bundle of the hyo-copulo-palatinus and the origin of the hyo-copulo-glossus. In one series of sections it was inserted into the external surface of the first branchial arch somewhat dorsal to its fusion with the basal plate, but in another series the insertion was as above described.

On the right side of my large series of sections the cranio-hyoideus was vestigial, and failed to reach its usual insertion. The anterior fibres terminated mid-laterally on the hyoid arch about half way down this cartilage and opposite the dorsal border of the posterior extremity of the copulo-quadratus profundus, whilst the posterior fibres terminated opposite the dorsal margin of the posterior soft cartilage portion of the hyoid in the fascia of the dorsal border and dorso-internal surface of the copulo-quadratus superficialis.

It is difficult, as P. FÜRBRINGER says, to assign a satisfactory function to this small muscle. FÜRBRINGER regards it as a vestigial muscle representing a functional branchial muscle at a time when the first branchial arch was not fused either with the

* 1, p. 332.

cranial framework or with the basal plate. Its vestigial condition on one side described above supports this view.

28. *M. constrictor pharyngis.* (Figs. 2, 3, 11, *c. p'.*, *c. p''.*, *c. p'''.*)

J. Müller, *Constrictor des Schlundes* [second and third portions] (p. 260). *Zweiter Constrictor des Schlundes. Dritter Constrictor des Schlundes* (p. 324). *Constrictor pharyngis* (p. 276).
Allis, *Constrictor œsophagei* (p. 334).

A very long powerful muscle, which, perhaps arbitrarily, may be divided into three sections which I have found to be separated by small breaks, as shown in fig. 3. The second and third divisions, however, may not be sharply differentiated.

First Division (*c.p'.*).—A few of the most anterior fibres may arise from the posterior extremity of the auditory capsule. In the sections none of the fibres arose from the capsule, but the origin commenced on the tough vascular fascia covering the post-auditory parachordals laterally. From here the origin extends downwards, backwards, and slightly outwards, first passing obliquely across, and at the same time arising from, the dorso-lateral surface of the notochord, until it arrives at the lateral surface of the chorda, and in a 34½ cm. Hag, 2 mm. from the exposed ventral margin of the latter. It thus reaches the place where in transverse section the inner free surface of the parietalis meets the chorda. In front, this is about half way down the latter, but behind, the parietalis more and more involves the chorda, although it never completely encloses it ventrally, even in the tail.

The origin now passes straight backwards parallel to the chorda, and arising from the superficial internal fascia of the parietalis—at first in the angle formed by this muscle with the chorda, but behind moving out laterally away from the latter. In the above Hag the origin extended over an area of 22 mm. From the origin the fibres strongly converge, most of them passing forwards and downwards in a curve round the lateral wall of the gut. The anterior fibres describe a graceful curve, with the concavity looking forwards, and the muscle covers the pharyngeal basket *externally* from the first branchial arch backwards, except for the most ventral third of this arch. The general appearance of this part of the muscle closely resembles an open fan. The insertion (hidden by the copulo-quadratus superficialis) is as follows :—(*a*) the fibres forming the most anterior sixth are inserted into the *posterior* surface of the most ventral 3 mm. of the first branchial arch, *i.e.* where it fuses with the middle segment of the basal plate. *Cp.* the connection of the cranio-hyoideus, the hyo-copulo-palatinus, and the hyo-copulo-glossus with this portion of the first branchial arch; (*b*) a few fibres are inserted into the dorso-external surface of the root of the lower division of the second branchial arch (when present, as I now believe it generally is*) just where it fuses

* Cp. Part I. p. 763. Since my first Part was published I have dissected a *Myxine* in which the lower division of the second branchial arch fused with the upper exactly as shown for *Bdellostoma* by Ayers and Jackson in their fig. 6. On pp. 763–4 of my first Part I state that this fusion has never been seen in *Myxine*. It is, hence, interesting to record it now.

with the first branchial arch; (*c*) the greater part of the fibres, however, are inserted into the dorso-lateral free border of the U-shaped posterior segment of the basal plate from its commencement to the beginning of the taper, *i.e.* to the commencement of the copulo-copularis. The whole insertion extended over 8 mm.

In the sections the insertion of the first division of the constrictor pharyngis was as follows:—the anterior fibres were wedged into the angle formed by the fusion of the first and second branchial arches ventrally, but the insertion was clearly more into the first than into the second branchial arch. The insertion then leaves both arches and passes on to the dorso-external surface of the posterior segment of the basal plate immediately below the second branchial arch. As, however, the latter rises, the muscle follows it until it reaches its characteristic insertion into the summit of the posterior segment immediately above and internal to the insertion of the copulo-quadratus superficialis.

Second Division (*c. p″.*).—This may be distinguished from the first division by its different insertion. In the sections, however, the separation of these two divisions was not so obvious, but I was able to establish it, especially as the fibres of the first division appeared to be larger than those of the second. The second division is not so compact as the first, and consists of a number of discrete fasciculi, which, however, continue the same origin backwards, *i.e.* from the superficial internal fascia of the parietalis, not far from the middle line. The origin, in the specimen above, extended over 16 mm. The fibres, slightly converging, pass sharply forwards and somewhat downwards and outwards, to be inserted into the external fascia of the *dorso-lateral* region of the copulo-copularis from its pointed extremity backwards. The insertion extended over 15 mm.

Third Division (*c. p‴.*).—This is not present in *Bdellostoma*, unless, as seems certain, J. Muller's first loop of the constrictor of the gills partly or entirely represents it. The third division is not so sharply defined as the other two, and the distinction may be difficult to draw in occasional specimens. It is, however, more compact than the second division, and has often a different origin behind and a slightly different insertion. In the sections, I was not able to distinguish between the second and third divisions, as there was no difference either in the origin or in the insertion. In the specimen shown in fig. 3 (but which, however, seems to be exceptional), about the first half of its fibres continued the previous origin backwards from the superficial internal fascia of the parietalis, as in the first and second divisions. The posterior half, however, arose from the ventral surface of a ligamentous sheet despatched forwards from the constrictor of the gills to the dorsal superficial internal fascia (cp. fig. 3). The whole origin extended over 11 mm. Hence, whilst the anterior fibres of this division pursued a course similar to that of the second division, the posterior fibres passed at first forwards over the afferent duct of the first gill pouch, and internal and dorsal to the pouch itself, and then downwards and outwards to reach their insertion. *All* were inserted into the external fascia of the copulo-copularis of the *dorsal* region, near the

middle line in the specimen now described, and over its last 16 mm. I have never seen the fibres of this division inserted into the protruding end of the longitudinalis linguæ. In most dissections, and also in the sections (cp. fig. 2), the posterior fibres of this division were the *direct continuation* of the dorsal fibres of the constrictor of the gills. If, therefore, in fig. 3 the ligamentous area between these two muscles remained muscular, and there was hence no origin from the dorsal fascia, this condition would be reproduced. In other words, the posterior fibres, instead of arising from the dorsal superficial internal fascia, more usually course longitudinally at the side of the gut, and are unquestionably simply the continuation forwards of the dorsal fibres of the constrictor of the gills, and, strictly speaking, are a part of that extraordinary muscle. This, as above mentioned, is borne out exactly in the sections, where the most posterior bundle of the constrictor pharyngis is clearly a portion of the constrictor of the gills, and constitutes the first loop of this muscle in connection with the first gill sack (cp. the Chart, fig. 2). The ligamentous sheet referred to above is absent.

The bearing of these facts on the question of the morphology of the constrictor pharyngis is discussed in the section on the constrictor of the gills, and we need only note here that the absence of any means of distinction between these two muscles indicates that they are essentially parts of one and the same branchial muscle, which, on the loss of the anterior gills, became modified in front as the constrictor pharyngis.

The first part of J. MÜLLER's constrictor of the pharynx = my cranio-hyoideus. His second and third parts = part I. of my C. pharyngis. The second part of the latter muscle in *Myxine* is thus absent in *Bdellostoma*, judging from J. MÜLLER's description, whilst the third section in *Myxine* (at least in part) = J. MÜLLER's first loop of the constrictor of the gills in *Bdellostoma*.

It is stated that the constrictor pharyngis, by drawing the basal plate and "tongue" muscle complex upwards and backwards, presses the gut against the parietalis and notochord, and thus occludes it.

29. *M. constrictor branchiarum et cardiæ*, F.J.C. (Figs. 2, 3, 13, *c. b. c.*, *c. b. c'.*, *c.b.c''.*, numerals *1–14*).

J. MÜLLER, *Constrictor der Athemorgane + Constrictor (Sphincter) der Cardia (Constrictor cardiæ)* (pp. 270 and 273). *Constrictor der Kiemen und der Cardia* (p. 328).

As the above two muscles of J. MÜLLER are both parts of one series, I propose to consider them together under the above name. Further, my description of this muscle is based largely upon dissections, as a detailed reconstruction of this maze from the sections, after spending the whole of one long vacation in repeatedly dissecting it, was a Quixotic task I had not the courage to face. I have, however, prepared a chart which illustrates the general anatomy of the muscle in the sections, a few notes on which will be appended to the present description.

This very remarkable and unique muscle varies to such an extent, at times even in its general arrangement, that no typical description is possible. Hence the present account has not been generalised, but details the conditions as found in a perfect specimen fixed in formol-alcohol. The result of this fixative is to whiten the tissues generally, and, so far, to keep them white. Hence the present muscle, always very difficult to dissect, is too white for accurate investigation. This, however, is easily remedied by soaking the specimen in very dilute chromic acid, which colours the muscles first yellow and then brown. A number of individuals were dissected, and the more important variations are recorded in the following description.

When a lateral incision is made through the body-wall at the region of the club-shaped muscle and gills and the flaps pinned back, it is seen that the space between the notochord and these structures is occupied by a quantity of adipose tissue. When this and the vagus nerve are removed from the roof of the club-shaped muscle, the oblique fibres of the constrictor pharyngis are exposed. On turning now to the gill region, the four anterior gills are seen, more or less faintly, showing through a layer of adipose tissue, which is deposited most densely in the depressions between the gills and between their ducts, so as to render the surface of the branchial region quite level. On removing this tissue, partly with a fine needle and partly by brushing it away, we see the whole of the first gill and decreasing portions of the next four lying in their gill sacks, which are usually more or less filled with blood.* The last gill and the greater part of the fifth are covered by a thin sheet of muscle, the fibres of which (cp. especially fig. 13, *c. b. c.*) course downwards and sharply forwards, becoming more and more horizontal towards the posterior end of the muscle, until the fibres at the ventro-posterior region are quite horizontal.

In some specimens this sheet of muscle was so reduced as to be practically absent. It is not present in *Bdellostoma* according to J. Müller, where only the loops are visible over the gill sacks.

At the posterior margin of the sheet there were a few fibres passing almost vertically downwards but slightly backwards on to the posterior surface of the ductus œsophago-cutaneus (fig. 13, *11*, and *d. æs. ct.*). The sheet meets the corresponding one of the other side at a somewhat irregular linea situated roughly in the mid-dorsal line. In *Bdellostoma*, according to J. Müller, there is an incomplete longitudinal fissure in the middle line, and the somatic arteries emerge at the lacunæ. He further states elsewhere that there is a crossing of the fibres at the mid-dorsal line in *Bdellostoma* and *Myxine*, so that the portion "was nach hinten auf der rechten Seite herabsteigt, ist die Fortsetzung der Fascikel, die vorn links heraufsteigen und umgekehrt" (p. 272). I have not seen any trace of this in *Myxine*.

The systemic aorta (*s. ao.*) passes *underneath* the two opposed sheets, *i.e.* between them and the gut. The somatic arteries, therefore, have to perforate the muscle in order to reach the back (cp. figs. 3, 13). In the specimen now described three such

* Cp. Cole, 5, p. 325.

arteries were given off—the anterior two emerging to the left of the median linea and the third to the right. In front of and behind the muscle the aorta emerges to become opposed to the notochord, *i.e.* its normal position. Ventrally the muscle extends so far as to cover the whole of the last gill and the greater part of the fifth, and also the last three ductus branchiales externi. Its ventral margin may be quite regular (cp. fig. 13) or very ragged (J. MÜLLER evidently saw this latter condition, and cp. the Chart, fig. 2), and the whole of this margin may be connected by a thin ligamentous sheet with the body-wall, either exactly opposite the dorsal border of the obliquus or the ventral border of the parietalis, or the posterior portion of the muscle may extend even further downwards so that the sheet is attached behind to the body-wall opposite the outer edge of the rectus.

Dorsally, the sheet-like portion of the constrictor extends much further forwards than ventrally—reaching as far as the second gill. Opposite the fourth gill it bifurcates, sending forward on each side a narrowing muscular limb (cp. fig. 3, *c. b. c'.*), separated by a median space from that of the other side. This limb, as shown in the figure, was in this specimen separated from the main portion of the sheet by a ligamentous partition, but this was certainly not the case in other individuals. In one example the two limbs were connected by a dorsal transverse muscular bridge, itself with a median longitudinal partition, and the whole anterior portion of the muscle was modified. The anterior limb above passed forwards and slightly downwards, becoming gradually narrowed, until over the second gill it merged into a gradually narrowing ligament which curved upwards and forwards to be inserted into the superficial internal fascia of the parietalis at the side of the notochord. This ligament, which is certainly of exceptional occurrence, had a curious connection with the posterior fibres of the third portion of the constrictor pharyngis, these fibres arising from the ligament, and curving forwards over the first gill to reach their insertion on the copulo-copularis (cp. the constrictor pharyngis).

The arrangement just described seems to indicate that the third portion of the constrictor pharyngis, if not the first two, corresponds to a modified loop (or loops) of the constrictor branchiarum. If so, they would represent the loops in connection with the anterior or lost gills, the first adult gill being otherwise without a loop. We must, however, not forget that the last loop of all, *i.e.* the one immediately in front of the ductus œsophago-cutaneus (figs. 2, 3, 13, *6*), is also unconnected with a gill in the adult. This view is strikingly borne out in most specimens, as there is no break whatever between the two muscles (cp. the Chart, fig. 2), the only difference being that instead of the fibres of the constrictor branchiarum passing on to the parietalis, they meet each other in the middle line over the gut, as already figured and described for *Myxine* by J. MÜLLER. Further support is to be found in the condition in *Bdellostoma*, for the third division of the constrictor pharyngis of *Myxine* unquestionably includes J. MÜLLER's first branchial loop of *Bdellostoma*.

The dorsal anterior limb of the constrictor sends downwards two muscular loops

(fig. 3, *1* and *2*), but both loops were in the specimen now described, and as shown in fig. 3, separated from the limb by thin ligamentous septa, which, however, judging from my other dissections, are of exceptional occurrence, in which case the fibres of the loop are directly continuous with those of the limb, a number of fibres in the latter turning sharply downwards at right angles to form the loop. In one specimen all the loops were exceedingly reduced; nevertheless the ventral longitudinal tract (figs. 2, 3, 13, *7*) was well developed. This shows that the latter tract has an existence independent of the loops—which is to be expected, seeing that the first loop, in some cases the fourth and fifth (cp. fig. 13), and generally the fifth, do not contribute any fibres to the tract. In the same specimen I found that the first loop, however, *did* unite with the ventral tract, some of the fibres passing backwards with the tract, and the others passing forwards with it to the usual insertion of the loop on the longitudinalis linguæ. Incidentally, we may here note that the second loop of *Bdellostoma*, corresponding to the first of *Myxine*, does *not*, according to J. MÜLLER, reach the longitudinalis linguæ.

First Loop (*1*).—Passes downwards and forwards in a curve over the external face of gill 2, then *under* the first efferent gill duct, not far from its origin from the gill, and finally bends straight forwards to fan out on the lateral fascia of the longitudinalis linguæ. In one specimen this insertion was ligamentous, and not muscular, as it generally is. In *Bdellostoma* the loops are said to course in the depressions between the gills. I have frequently seen this in *Myxine* also. A very striking difference, however, is that in *Bdellostoma*, according to J. MÜLLER, there is no ventral longitudinal tract, but all the loops are attached to the *ventral belly-wall* opposite the external branchial apertures. In many specimens of *Myxine* the loop included a number of fibres (as shown in fig. 3) which did not pass underneath the efferent gill duct, and which fanned out in the fatty tissue covering the gills; but in other individuals the first loop consisted solely of fibres for the longitudinalis linguæ. We do, however, find the non-ventral fibres of the loops, when present, more and more spread out as we pass backwards, so that the continuous posterior sheet may be regarded as having been formed by these fibres of two or more loops fusing together.

Second Loop (*2*).—Passes downwards and slightly forwards over the external face of gill 3, crosses over the origin of its efferent duct, then dips underneath first the second and then the first efferent ducts, to finally pass over into the ventral longitudinal tract. The latter varies considerably, and it may be very greatly reduced on one or both sides so as not to reach the second and third loops, which consequently terminate in the fatty tissue below their respective gill ducts. The formation of this ventral tract will be described subsequently. Most of the fibres of the second loop pass forwards with the tract, but a few of them turn backwards along it. This, however, here and in the other loops, is subject to variation, and the fibres of the loop may be equally divided, one half passing forwards and the other half backwards, and so on. The ventral tract, after receiving loop 2, continues its course straight forwards, and in the specimen now described terminated in two ligamentous fans, the

dorsal one of which turned upwards to become attached to the fascia at the posterior end of the longitudinalis linguæ, whilst the ventral and larger one bent downwards to effect an extensive connection with the internal surface of the rectus muscle near its outer margin. This termination just described is, however, by no means of general occurrence. The same remark as to the occasional presence of non-ventral fibres applies to the second as well as to the first loop.

Third Loop (*3*).—Immediately behind the origin of the anterior dorsal limb the main body of the constrictor despatches ventrally a third loop. This loop, in all the specimens I have dissected, includes a greater or lesser number of the non-ventral fibres. These fibres were very numerous in the present case, and by fanning out in front and behind largely covered the external surfaces of gills 4 and 5. The whole of the fibres of the loop were marked off at their origin from the major portion of the muscle by a ligamentous partition, but this is by no means of universal occurrence. The ventral portion of the loop passes external to the origin of efferent gill duct 4 almost straight downwards, but slightly forwards, then slips under the efferent ducts 3, 2, 1 in the order mentioned, and finally goes over into the ventral longitudinal tract in much the same way as loop 2.

The last two loops, owing to their origin from the internal surface of the now continuous posterior sheet of the constrictor some distance above its ventral border, are consequently not entirely seen until the covering sheet has been turned dorsally or its ventral portion removed. Hence in fig. 3 the latter has been done in order that all the loops may be included. The behaviour of these two loops also varies considerably.

Fourth Loop (*4*).—Passes external to the origin of efferent duct 5, and then downwards internal to the ducts 4, 3, 2 1. Ventrally it may go over into the ventral longitudinal tract, the fibres diverging to accompany the latter backwards and forwards (as shown in fig. 3), or it may assist in forming the internal portion of the ventral insertion (as shown in fig. 13, *8*). In the latter case the loop distinctly bifurcated, one limb passing into the ventral insertion, and the other coursing backwards as described under the *ventral insertion*, *2*.

Fifth Loop (*5*).—Courses external to the origin of the efferent duct 6, and then ventrally internal to ducts 5, 4, 3, 2, 1. I have never seen this loop connected with the ventral longitudinal tract except by a very few fibres which it occasionally despatches to it (but cp. the description of the sections). It always passes external to the tract and on to the inner portion of the ventral insertion (figs. 3, 13, *8*), but some of them turn backwards as described under the *ventral insertion*, *2*.

The last two loops are very differently arranged in *Bdellostoma*, according to J. Müller. Here they bend right round and fuse in the mid-ventral line over the cardiac aorta on the ventral surface of the constrictor cardiæ, so as to form a distinct sphincter system of their own. Also in *Myxine* itself, according to Müller, the last three loops fuse up to form on each side a ventral longitudinal tract, which, however, courses

only backwards, none of the fibres passing forwards as above described. I have seen this condition also, but only in one specimen.

Ventral Longitudinal Tract.—The fibres of the two tracts, when traced backwards, are seen to gradually converge as they approach the external branchial openings. Most of their fibres arise immediately behind these openings—the fibres of the two sides meeting at the mid-ventral line, where they are attached to the cardiac portion of the constrictor. The tract also receives dorso-ventral fibres which bend round on to it from above behind the ductus œsophago-cutaneus, as described below, and also a few fibres from the dorsal longitudinal tract, which pass round in a curve into it behind the above ductus instead of terminating at the mid-ventral line, as described below. The only traces I have seen of any decussation in the constrictor is that a variable number of fibres of, say, the right dorsal longitudinal tract may cross over into the left ventral longitudinal tract, and *vice versa*.

We must now enter into the details of the anatomy of the posterior region of the constrictor—a subject both difficult to understand and to describe. To get at the facts it is necessary to remove the constrictor *en bloc* and carefully clean it up. This is not an easy dissection, but it is the only way to understand the muscle. To do it, you remove the whole of the branchial region from the body-wall, leaving the rectus muscle attached to the latter. Then remove first the efferent gill ducts and then the gills themselves on each side, and finally snip through the large loop on the left side in front of the ductus œsophago-cutaneus, so that the latter itself may be cleared away. The constrictor is now ready to be isolated. Make a longitudinal incision through the thickness of the muscle a little on one side of the mid-dorsal line, and with a fine needle separate the constrictor from the gut, which may then be lifted out. You now have the whole of the constrictor in one piece, so that both inner and outer surfaces may be investigated, and further examination effected under the higher powers of the dissecting microscope.

The *cardiac portion of the constrictor* (figs. 2, 3, 13, *c. b. c″.*) extends a variable distance behind the gill region over the gut—in an average specimen about 5 mm. In one case the fibres were separated at the mid-dorsal and mid-ventral lines by a ligamentous septum. The fibres are loosely arranged behind, but are more compacted in front. They course transversely round the gut, but usually slightly obliquely forwards from above. Dorsally and in front the fibres surround the exit of the systemic aorta so that the latter vessel has a small constrictor of its own. In front of this region dorsally and on each side the fibres again diverge to allow the exit on the left side of œsophageal vessels opening into the left anterior cardinal (figs. 2, 3, 13, *12*), and on the right side of similar vessels opening into the anterior portal vein, which is a smaller vessel, but occupies a similar position to the anterior cardinal of the other side. These openings may be provided with definite constrictor fibres. The mere divergence of the fibres could of course perform the same function, but not so effectively as a special constrictor. Ventrally in front the cardiac portion of

the constrictor is covered by the posterior extremities of the ventral longitudinal tracts, which partly arise here near or at the mid-ventral line, and between or just behind the external branchial apertures.

Anteriorly the cardiac portion of the constrictor passes imperceptibly into the branchial portion (*c. b. c.*), so that no distinction between the two portions is possible. The fibres now begin to course in various directions, but the following general tendencies may be distinguished.

Externally, Left side :—

1. A small slip may be given off to the internal fascia of the obliquus (fig. 13, *9*).

2. A number of fibres bent round ventrally and anteriorly to complete the formation of the ventral longitudinal tract (for remainder, see above).

3. A large number of fibres course downwards and forwards round the postero-internal surface of the ductus œsophago-cutaneus (figs 2, 3, *10*) to partly form the muscular tube through which the ductus passes, and finally to assist in forming the large external portion of the ventral insertion (figs. 2, 3, 13, *8'*).

4. A small slip (figs. 2, 13, *11*) passes downwards and slightly backwards on the posterior surface of the ductus œsophago-cutaneus, to be mostly inserted into the ventral posterior process of the cartilage of the ductus (fig. 13, x^3.)

5. We now come to the region where the fibres terminate below in a ventral border, which may be attached to the body-wall by a ligamentous sheet, as above described. Here the fibres nearest this ventral border, after previously coursing downwards and slightly backwards, turn forwards at a right angle and travel parallel to the ventral border (fig. 13). A few fibres, however, here pursue a rectangular course (fig. 13, part of *11*), *i.e.* they pass first of all posteriorly parallel to the ventral border, and then, near the posterior surface of the ductus œsophago-cutaneus, they turn down at a right angle to be inserted as the slip (4) just described, and also into the wall of the ductus near its external opening. As we go further forwards the fibres of the posterior region of the branchial portion of the constrictor bend at a gradually increasing angle until finally attaining the downward-forward direction characteristic of the greater part of the muscle, as already described.

Externally, Right side :—

1 and 2. As on left side.

3. We find similar fibres coursing downwards and forwards, but this time round the postero-internal surface of the last efferent gill duct, to form the external portion of the ventral insertion. As these fibres course morphologically in front of the ductus œsophago-cutaneus, they cannot of course represent the fibres of paragraph 3 of the left side. They correspond in fact to the larger sixth loop of the left side, to be described below, and which passes between the last efferent gill duct and the ductus (figs. 2, 3, 13, *6*).

4. Absent. 5. As on left side.

Internally, Both sides:—

When the internal surface of the muscle is examined it is seen that there are a number of fibres in addition to those appearing on the external surface. Ignoring the scattered fibres running in various directions, and which may occur on the external surface also, we notice, particularly in the mid-dorsal region, a large numbar of fibres coursing longitudinally, which may be more or less diffuse, or which may be collected together into a definite tract on each side of the mid-dorsal line. I shall call this the *dorsal longitudinal tract.* It increases in thickness as it passes backwards. In front, these fibres pass over into the anterior muscular limb already described (*c. b. c'.*). It is now seen that the loops are not entirely formed by the dorso-ventral fibres of the outer muscular sheet of the constrictor, but receive from, and give fibres to, the dorsal longitudinal tract. The greater majority of the latter fibres pass from the tract on to and along the posterior margins of the loops. From the anterior margins of the loops a few fibres are given off which accompany the tract forwards. It would appear, therefore, from this, that many fibres of the loops have no beginning and no end, but course round in circles formed by the dorsal and ventral longitudinal tracts and the loops. Behind, the dorsal tract behaves as follows :—

1. A few of the fibres may pass straight backwards, ventral to the vascular gap (figs. 2, 3, 13, *12*), and along the inner surface of the cardiac portion of the constrictor.

2. Most of the fibres curve downwards in front of the vascular gap (*12*), and behind the ductus œsophago-cutaneus on the left side and the last efferent gill duct on the right, to meet at the mid-ventral line on the gut *internal* to the origin of the ventral longitudinal tract, and thus continue forwards the cardiac portion of the constrictor.

3. On the left side a number of fibres were contributed to the sixth and largest loop (figs. 2, 3, 13, *6*), which passes obliquely forwards in front of the ductus œsophago-cutaneus, and which varies less than any other portion of the constrictor.

4. A few fibres may bend forwards and go over into the external portion of the ventral insertion (fig. 13, *13*).

Sixth Loop (*6*).—As this has already been described on the right side, the present account applies to the left side only. It arises from the inner surface of the outer branchial muscular sheet, and passes downwards and forwards into the outer portion of the ventral insertion in front of and external to the ductus œsophago-cutaneus, and internal to the last efferent gill duct. It is constituted as follows :—

1. Some dorso-ventral fibres from the internal surface of the muscular sheet above.

2. A number of fibres from the dorsal longitudinal tract, as above described.

3. The fibres forming the definite *constrictor of the ductus œsophago-cutaneus* (figs. 2, 3, 13, *14*), which accompany the sixth loop in front of the ductus, but leave it above and below to complete the sphincter by curving round the back of the ductus.

For the insertion of this loop, see below.

That the sixth loop is serially homologous with the preceding five is borne out by

J. MÜLLER's description of *Bdellostoma*, where this loop has precisely the same relations as most of the others. In this region and that of the ventral insertion MÜLLER figures and describes in *Myxine* a very obvious and elaborate decussation of the fibres round the gut, both dorsally and ventrally, but the description is by no means clear (and indeed he recognises this himself), and the figures are too small and vague to be of much assistance. It is improbable that MÜLLER was mistaken in his facts; and as I have never seen any decussation of fibres except the slight one mentioned above, this can only be regarded as another of those extreme variations which this perplexing muscle exhibits. [Since this was written, however, I have found a distinct ventral decussation in one of my series of sections. The paired tracts forming the inner portions of the ventral insertion, after passing backwards under the gut, fused first with each other and then with the cardiac portion of the constrictor in such a way that each tract sent fibres both to its own and to the other side of the gut.]

Ventral Insertion.—We are now in a position to describe the ventral insertion of a large number of the fibres of the branchial portion of the constrictor. On each side a fan-like tract collects in front of the external branchial aperture (figs. 2, 3, 13, *8*, *8'*) and passes *between* the two recti muscles, to be inserted into the internal fascia of the obliquus at the mid-ventral line. I have seen in some cases a few slips inserted into the internal fascia of the rectus itself, but generally the latter muscles may be entirely removed without in any way interfering with the insertion. J. MÜLLER describes the fibres as inserted into the rectus muscle on each side of the middle line. Apart from the few slips mentioned above, I have never seen this, either in dissections or sections [but cp. the description given below of the sixth loop in the sections], and should have concluded it to be an error on MÜLLER's part, were it not for the extensive variation characteristic of the constrictor generally. The insertion consists of an outer and an inner portion on the left side, made up from the following sources :—

1. Outer Portion (figs. 2, 3, 13, *8'*).—The last or sixth loop (*6*) forms the greater part of this section, but a tract is usually contributed by the fibres that curve round the internal surface of the ductus œsophago-cutaneus from behind (cp. fig. 3), and also a few longitudinal fibres reach it straight from their origin on the ventral surface of the cardiac portion of the constrictor at the side of the origin of the ventral longitudinal tract.

2. Inner Portion (figs. 2, 3, 13, *8*).—This is not invariably separate from the outer portion, but always more or less so. It consists of a large number of fibres which curve round the ductus œsophago-cutaneus as above described, of many which pass straight on to it from the ventral surface of the cardiac portion of the constrictor, and of fibres from the loops 4 and 5. These loops may be entirely connected with the inner portion of the insertion (as in fig. 13, and, as I believe, is more frequently the case), or they may be more or less connected with the ventral longitudinal tract. In any case, however, all their fibres do not pass into the ventral insertion, or forwards into the ventral longitudinal tract, or both, but a varying number curve backwards

and upwards into the dorsal longitudinal tract, and some I have traced to an origin on the ventral surface of the cardiac portion of the constrictor.

On the right side, owing to the absence of the ductus œsophago-cutaneus, the ventral insertion is naturally the smaller by the fibres which are contributed to it on the left side by the fibres of the ductus. Hence the outer portion of the insertion is formed practically entirely by the last or sixth loop. The inner portion resembles that of the other side.

The physiology of this complex muscular apparatus can, of course, only be determined by experiment. Two points, however, are quite clear at once: (1) the œsophagus can be powerfully constricted immediately behind the branchial region so as to prevent the entrance of respiratory water into the gut; (2) the ductus œsophago-cutaneus, lying as it does for the most part in a strong muscular tube, as well as possessing an abundant intrinsic musculature, can also be occluded. For the rest, the muscle is subject to so much variation as to indicate that it is a vestigial structure of little, if any, physiological importance. It certainly cannot in the average *Myxine* "discharge the water taken in by the breathing organs" (J. MÜLLER, p. 276). For this the powerful intrinsic musculature of the gills and their ducts is amply sufficient. It is quite possible, however, that it may be concerned in controlling the blood-pressure in the elaborate system of vascular spaces surrounding the gill region. MÜLLER's statement of the physiology of the gill apparatus is evidently based merely on its anatomy, and he further does not seem to be aware that the respiratory water normally reaches the gills through the nasal tube.

I append the following notes in explanation of the reconstruction of the general anatomy of the left side of the constrictor muscle from my large series of sections (fig. 2). I do not here or elsewhere include the intrinsic musculature of the gut and gill apparatus, which will be described in my next Part when these structures are under special consideration.

The posterior external sheet (*c. b. c.*) has a very ragged ventral border, and, judging from the structure of the loops as we pass backwards, is evidently formed by the fusion of those fibres of the last three loops which are related to the gills, *i.e.* the non-ventral fibres. These become more numerous and diffuse from before backwards, and finally fuse up to cover the last gill and the greater portion of the fifth. There are numerous lacunæ here and elsewhere (not all shown in the Chart), the largest (*12*) transmitting the veins from the gut opening into the anterior cardinal on the left side and the anterior portal on the right. The lacuna is smaller on the right side. The two halves of the constrictor fuse dorsally at about 2970, but in front of this they are connected by three transverse bridges—a narrow anterior and posterior one, and a wide intermediate one. The constrictor envelops the systemic aorta (*s. ao.*) at the mid-dorsal line as above described. In front the muscle forks in the usual way into the pair of anterior limbs (*c. b. c'.*), and each of these passes, without any obvious line of

demarcation, into the posterior section of the constrictor pharyngis (*c. p'''.*). I have taken the boundary to be where the first loop merges into the anterior limb, but this is an arbitrary distinction.

First Loop (*1*).—On the left side this is somewhat similar to the condition represented in fig. 3, but on the right it did *not* reach the longitudinalis linguæ (*l. lg.*), but fanned out on the dorso-lateral surface of the external wall of the second pleural sack in front of its efferent gill duct. A small bundle was sent backwards on to the root of the gill duct. Hence, on the left only the ventral fibres were present, and on the right only the non-ventral, the two sides together representing the fibres which may be present on each side, as shown in fig. 3.

Second Loop (*2*).—Takes no part in forming the definitive ventral longitudinal tract (*7*), but terminates freely in front in the fatty areolar tissue slightly below and to the side of the cardiac aorta at about the level of the origin of the second afferent gill duct. This loop despatches an anterior slip to the second efferent gill duct, another anterior and smaller one at the same level to the fatty areolar tissue external to this duct, and a third postero-ventral one to the *first* efferent gill duct. On the right side the loop terminated in front mostly on the inner surface of the first efferent gill duct. There seems little doubt that the ventral forking of the loop corresponds to the anterior and posterior fibres contributed to the ventral longitudinal tract.

Third Loop (*3*).—Inserted by a very narrow anterior and a very wide posterior bundle into the superficial internal fascia of the parietalis, not far from its ventral border and in front of the fourth gill sack.

Fourth Loop (*4*).—Inserted in front into the superficial internal fascia of the parietalis in the same way and at the same level as the third loop.

Behind the fourth loop are seen the five large processes into which the ventral border of the posterior external sheet of the constrictor is prolonged. These are mostly inserted into the internal fascia at the junction of the ventral margin of the parietalis with the obliquus. The insertions of the third and fourth loops just described continue this series forwards.

Ventral Longitudinal Tract (*7*, *7'*).—The sections throw considerable light on the nature of this tract. The postero-ventrally coursing bundles, forming part of loops 3 and 4 and the whole of loop 5 (*3*, *4*, *5*), correspond unquestionably in every detail with the ventral bundles previously described from dissections, of which the third and fourth may contribute to the ventral tract, and the fifth usually does not. In the sections the ventral bundles of loops 3 and 4, after a typical course, combined to form a separate or anterior section of the ventral longitudinal tract (*7*), which, passing forwards immediately ventral to the first efferent gill duct, terminates in front on the obliquus muscle not far from the lateral margin of the rectus. The greater part of this section, *i.e.* between the points of entry of the loops, is formed of fibres from loop 3 passing backwards and of loop 4 passing forwards. Both loops, on entering the section, despatch fibres forwards and backwards. Posteriorly the section splits, leaving a lacuna

(cp. also fig. 13, *4*), part of the fibres passing straight downwards, internal to the posterior section of the tract, to assist in forming the inner portion of the ventral insertion (*8*), and the remainder coursing backwards, immediately dorsal to the other fibres of the inner portion of the insertion, and forming a bundle which remains distinct from the latter up to about 3078, but which then merges into it.

The *Fifth Loop* (*5*) separates itself from the inner surface of the posterior external sheet of the constrictor opposite the middle of the last gill, and passes in a curve downwards and slightly backwards. It finally bifurcates into a short postero-ventral division, which penetrates between the posterior extension of the anterior section of the ventral tract and the remaining fibres of the inner portion of the ventral insertion to terminate on the internal fascia of the latter without reaching the ventral insertion, and into an anteriorly directed division. This latter constitutes the posterior section of the ventral longitudinal tract (*7′*), which courses forwards immediately under the anterior section, but which, except for a few connecting fibres, as shown in the Chart, is quite distinct from it. The posterior section terminates anteriorly on the internal or dorsal surface of the rectus muscle. On the right side the fifth loop splits as above stated, but the posterior division bends downwards and *forwards*, and forms the most anterior bundle of the inner portion of the ventral insertion.

The above facts show that the ventral longitudinal tract is not a definitive muscle, but is rather a complex, formed of the secondarily juxtaposed contributions from about three loops + other fibres, as above described.

The *Sixth Loop* (*6*), which is smaller than I found it in dissections, is detached from the internal surface of the posterior external sheet of the constrictor, and passes almost straight downwards to its insertion. This represents the outer portion of the ventral insertion (*8′*), but it differs very considerably from the insertion as I found it in dissections. In the first place, it is not only absolutely distinct from the inner portion, but entirely posterior to it. Then only two small bundles pass inwards and downwards between the two recti muscles at the mid-ventral line in the normal manner, most of the fibres being inserted into the lateral or outer margin of the left rectus. Posteriorly it receives the small special constrictor of the ductus œsophago-cutaneus (*14*), as above described.

On the right side the sixth loop is very reduced. It is continued from the ventral border of the posterior external sheet of the constrictor slightly below the ventral margin of the parietalis and at the transverse level of the posterior outline of the last gill. It then courses obliquely downwards and forwards, to be attached to the lateral margin of the right rectus. There is thus only a slight outer portion of the ventral insertion on this side. In dissections I have sometimes not found the sixth loop on the right side at all, and hence the outer portion of the ventral insertion may in some cases be entirely wanting on this side.

The inner portion of the ventral insertion (*8*) is formed partly by fibres from the third and fourth loops (+ the fifth on the right side), but largely by the definitive fibres

of the insertion. All these form a large paired tract which passes backwards internal to the gill and œsophageal ducts, and lateral to the cardiac aorta. As these tracts course posteriorly they spread out dorso-ventrally, and finally, together with the two recti below, by fusing at about the middle line under the gut, they form a complete muscular tube enclosing behind the vascular sinus surrounding the cardiac aorta. The mass then fuses with the posterior external sheet of the constrictor to form the cardiac portion of the muscle in such a way that fibres from *each* tract curve round *both* sides of the gut. There is thus a well-marked decussation, as mentioned above.

30. *M. parietalis*, F.J.C. (Figs. 1, 4, 5, 7, 8, 9, 14, *par.*)

J. Müller, *Rücken- und Seitenmuskeln* (p. 243).
M. Fürbringer, *Epibranchiale musculatur* (p. 627).

This is the muscle that constitutes the well-known alternating mytomes of the fish. Its division into dorsal and ventral portions (Parietalis dorsalis and Parietalis ventralis) by a horizontal septum stretching from the vertebral column to the lateral line, which obtains in other fishes, does not exist in *Myxine*, where this septum is wanting. Wikström,* however, considers the septum a secondary formation of little morphological importance, and J. Müller distinguishes "back" and "lateral" muscles in the parietalis of *Bdellostoma*, although this division is certainly artificial, as M. Fürbringer states. Wiedershiem considers the obliquus + rectus as representing the detached ventral musculature, and actually labels the dorsal border of the obliquus as the linea lateralis. Omitting the question of the morphology of the rectus, the parietalis of *Myxine* is in transverse section a single sickle-shaped muscle on each side (fig. 1), the two being separated mid-dorsally by a vertical partition arising from the cranium and neural tube, and passing over into the strong external fascia of the muscle. This septum is in front, over the cranium, wide from side to side and narrow behind, as shown in fig. 8. The parietalis terminates some distance from the mid-ventral line by a free border situated just above the slime sacks (fig. 1). The same conditions apply to *Petromyzon* for the region behind the gills, but within the branchial area dorsal and ventral parietal muscles have been differentiated.

In Fishes generally the parietalis does not extend further forward than the occipital region of the skull, but in *Myxine* it passes forwards over the membranous cranium until it almost reaches the posterior boundary of the nasal capsule (see figs. 8 and 9).

The parietalis, enclosed externally and internally by a stout fascia, the fibres of which in the outer one course obliquely downwards and *forwards*, is subdivided by the zigzag vertical partitions or *septa intermuscularia*† (ligamenta intermuscularia, J. Müller; inscriptiones tendineæ) into a number of muscle segments or myotomes. These septa

* *Anat. Anz.*, xiii., 1897, p. 401.

† I have avoided the term myocomma for the septum, as this term was used by the older anatomists to indicate the myotome itself.

pass through the entire thickness of the muscle, and hence the length of the muscle fibres, which course more or less directly longitudinally from one septum to another, is confined to the intervals between the septa. Hence, as WIKSTRÖM says (p. 406): "Ein jedes Transversal-septum fungirt also zugleich als Ursprungssehne für das eine Myomer (Muskelbauch) und als Endsehne für das andere, angrenzende." Further, the fibres on the two sides of any one septum are often placed exactly opposite each other, so as to be directly continuous except for the septum.

The course of the septa through the thickness of the parietalis, *i.e.* from the fascia superficialis externa to the f. s. interna, can be studied either by a series of longitudinal radial hand sections, or, and much better, by picking and brushing away the muscle fibres from a macerated specimen. It is then seen that the septa do not everywhere pass straight through the width of the muscle, *i.e.* at right angles to the long axis of the body, but follow largely an oblique course, as shown in fig. 14. A typical septum from the middle of the body may be divided into four parts, commencing at the back, as follows (cp. the figure):—1. Externally commences near the middle line, and passes obliquely downwards and forwards at a sharp angle. It penetrates the muscle almost straight downwards, *i.e.* vertically, at right angles to the surface at this region, but somewhat inwards, and is attached internally at the middle of its length to the skeletogenous layer of the neural tube, near the junction of the latter with the chorda. Both behind, and in front where it bends sharply on itself opposite the junction above and turns backwards, it does not reach the neural tube or chorda, and therefore has no internal attachment at these places. 2. As seen externally, passes sharply backwards and downwards. It penetrates in a curve with the convexity external and anterior, almost straight through the muscle, *i.e.* sub-horizontally, at right angles to its external surface, but somewhat inwards, to become obliquely attached to the skeletogenous layer of the lateral wall of the chorda. 3. Externally, passes almost straight downwards, but slightly forwards, and courses obliquely through the muscle in a forwardly-directed curve, with the concavity external and anterior, to become attached to the fascia superficialis interna. 4. Continues the external course of 3, and passes practically straight through the muscle, but slightly forwards, to become attached as 3. As the muscle is thinnest at this region, the septum is here very narrow. In the Lamprey, according to J. MÜLLER, the septa are much more oblique, so that in a transverse section one sees a greater number of them than in *Myxine*.

I have counted the number of the myotomes in the different regions of the body in six Hags taken at random, with the following results (see table, next page).

J. MÜLLER gives 109 as the number of myotomes in *Bdellostoma*.

I have found the first few myotomes to vary somewhat. For example, the first may be quite small and quadrangular, and situated immediately below the ventral border of the tentacularis posterior, or, as is generally the case, its dorso-posterior angle may be prolonged upwards and backwards under the ventral edge of the above muscle, in some cases as far as its posterior extremity, as shown in fig. 9. In these cases the normal

Size of Hag in cm.'s.	20½		22½		24½		26½		28		37	
Left and Right Sides.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.
Anterior to Branchial Pore . .	28	28	28	27	27	27	29	29	30	30	30	28*
Opposite Branchial Pore . . .	1	1	2	1	2	1	2	1	2	1	2	1
Between Branchial Pore and Cloacal Aperture	56	57	53	53	54	54	59	60	57	58	56	58
Opposite Cloacal Aperture . .	2	2	2	2	2	2	2	2	2	2	3	2
Post-cloacal	20	21	22	22	20	21	19	20	24	25	20	22
Total .	107	109	107	105	105	105	111	112	115	116	111	111

* Of these the first was partially subdivided into two, and obviously corresponded to the first and second of the left side. Hence there is really one more on the right side than on the left.

first myotome is doubtless the one with the posterior extension, the small quadrangular one being additional. I have, however, never seen any appreciable dorsal section to the first myotome except in one case (see fig. 9), where a few scattered fibres in front of the second myotome might have represented the dorsal portion of the first. When the first myotome is quadrangular it is entirely covered by the dorsal extension of the obliquus, but when the posterior extension is present, this is visible as far as it is developed after removal of the skin. In all cases the first myotome is considerably smaller than the succeeding ones, and never extends so far ventrally. According to J. Müller, the first myotome is attached to the "cartilage process at the anterior end of the tongue bone and to the cartilage of the ventral [fourth] tentacle." This is very different from *Myxine*.

The normal second myotome is in some exceptional cases, as stated above, preceded by two distinct myotomes, in which case, of course, it becomes the numerical third. The first is then very small, whilst the second represents the normal first myotome. The normal second myotome consists of two limbs, placed at about a right angle, with the apex directed posteriorly. The dorsal limb passes upwards and forwards behind the posterior extremity of the tentacularis posterior, but does not reach the mid-dorsal line (figs. 8 and 9). The ventral limb courses downwards and forwards, at first under the ventral border of the tentacularis posterior, but afterwards behind and below the first myotome. There is a distinct furrow between the second myotome and the tentacularis posterior. Myotomes three to about eight or ten vary in external appearance, and have the form indicated in figs. 8 and 9. From myotome ten up to, generally, about twelve from the tip of the tail, all the myotomes exhibit the following external conformation (fig. 5). At the side of the mid-dorsal partition there appears to be a continuous narrow muscular band, unbroken by any septa intermuscularia. If this, however, is examined carefully in Perenyi-fixed material, it will be seen that it is traversed by very faint septa, which pass very sharply backwards. The septa then become obvious, and turn sharply forwards at an acute angle, then backwards again at a somewhat less acute angle, and finally by an obtuse angle pass downwards and slightly forwards. This agrees substantially with J. Müller's description and figure of the *tail* region of *Bdellostoma*. On the body the arrangement is simpler, according to

him. The last twelve myotomes often exhibit a gradual simplification of this pattern, so that the last few septa appear as sinuous vertical lines. In other specimens, however, as shown in fig. 4, the pattern may be continued practically to the very extremity of the tail. The last myotome is a very small, irregular, and variable patch of longitudinal fibres at the tip of the tail. The slime sacks behind the cloaca, as described below, are partly covered dorsally by the myotomes.

The first myotome, *i.e.* of the small type, lies largely between the anterior dorsal extension of the obliquus and the copulo-palatinus, and arises from the fascia between these muscles. The succeeding myotomes, except those behind the cloaca, are all covered ventrally by the obliquus, but the dorsal and greater portions are seen at once on removal of the skin. The second, third, fourth, and fifth myotomes are thin dorsally, and roof over the membranous brain case, being closely attached to it. The anterior myotomes are also attached to the posterior extremity of the anterior process of the pterygo-quadrate, the superior and (the anterior end of) the inferior processes of the same, the auditory capsule, the dorsal portion of the hyoid arch, and the anterior end of the superior lateral cartilage. Below, the anterior myotomes cover the muscles of the head, pharynx, and the so-called "club-shaped muscle." Behind the fifth myotome the parietalis gradually thickens dorsally, where for the remainder of its length it is very fleshy, and attached to the roof and sides of the neural tube and the lateral surface of the chorda, from thence becoming thinner as it passes ventrally. From about the seventh to the twenty-third myotome a wide interval is left dorsally between the parietalis and the club-shaped muscle, in which space course the very diffuse second and third divisions of the constrictor pharyngis. This hiatus is directly continuous with the very large extra-branchial space, and the corresponding one at the dorsal region of the heart, abdomen, and tail, and is everywhere traversed by the silky adipose areolar tissue supporting nerves and blood-vessels. At the gill and cardiac regions the parietalis, together with the notochord, forms the lateral walls and roof of this space, whilst below it is bounded by the obliquus and rectus muscles. The parietalis, however, reaches its greatest development in the abdominal region. Here the muscles of the two sides are separated at the mid-dorsal line by a thin vertico-longitudinal partition arising from the roof of the neural tube. From thence the muscle extends downwards as a rapidly thickening mass at the side of the neural tube and chorda, being closely attached to these, and attaining its greatest thickness opposite the ventral surface of the latter (fig. 1). Here, with the chorda, it forms the roof of the abdominal tube. It now extends downwards, becoming gradually thinner, in order to terminate in a free border immediately over the slime sacks, and being only separated from the latter by the obliquus muscle. Here also it forms the lateral wall of the abdominal tube (fig. 1).

On the tail, where of course there is no body cavity nor any obliquus or rectus muscles, and where, apart from the transversus caudalis and the cordis caudalis, there is no other muscle present, there is a relatively greater development of the parietalis

above the neural tube, and a thinning at the side of the neural tube and chorda. In the anterior region of the tail the slime sacks occupy the position of the body cavity, and the parietalis extends externally about half way down on each side of the slime sacks. Such extension must, of course, be purely secondary. Dorsally, the muscle extends above the neural tube at the side of the median dorsal bar, where this exists, whilst behind the slime sacks it stretches below the chorda at the side of the median ventral bar, where it is best developed, and where it coincides with the ventral boundary of the body. It soon begins to thin down, first laterally and then dorsally, and finally terminates in a very small and often irregular myotome on the fused dorsal and ventral bars, slightly behind the posterior end of the spinal cord.

The function of the parietalis is to effect the sinuous movements by which the animal swims.

31. *M. obliquus*, F.J.C. (Figs. 1, 4, 5, 9, 10, *obl.*)

J. Müller, *Schiefe Bauchmuskel* (p. 246).
M. Fürbringer, *M. obliquus externus* (pp. 613 and 628).
Wiedersheim, *M. obliquus abdominis externus* (p. 232).

I have abbreviated the name of this muscle because it extends not only over the abdominal but also over the respiratory and cranial regions of the body. In a 31 cm. Hag it commenced 7 mm. behind the extremity of the snout as a thin sheet of fibres coursing obliquely in a curve downwards and backwards from the ventral edge of the tentacularis posterior, to which it is attached, and extending along about the middle third of the latter. This anterior more dorsal portion of the muscle entirely or largely covers the small first myotome and the ventral portion of the second (fig. 9). Behind the anterior 6 mm. the dorsal edge of the muscle descends to the more ventral level of the remainder of it, but throughout its whole course covers externally the ventral portions of the myotomes.

The obliquus is characterised in that portion of it in front of the branchial apertures by an extraordinary interdigitation of its fibres ventrally. On the abdomen the fibres arise as one continuous sheet from the superficial external fascia, but as the latter passes externally to the slime sacks and the obliquus internally to the same, the two are separated for a time. Mid-ventrally the obliquus terminates *without overlapping* at a ligamentous linea which is connected with the superficial fascia, the latter curving upwards and inwards over the median surfaces of the slime sacks to meet it. In front of the abdominal region, however, the fibres of the obliquus, as they approach the mid-ventral line, are first of all collected into definite fasciculi of very variable size, and these terminate, not at a mid-ventral linea, but are continued for some little distance over the median line on to the opposite side of the body to which they belong (fig. 10). The extent of the crossing is greatest immediately behind the mouth, *i.e.* at the anterior end. From thence it irregularly narrows down to a point at the respiratory apertures,

so that there is no sharp transition between the simple and crossing portions of the muscle. In the pre-abdominal portion of the obliquus, therefore, there is ventrally a very curious interlacing, extending from immediately behind the mouth to the branchial apertures, where it ceases, the fasciculi of one side having to pass underneath the fasciculi of the other side before emerging on to the surface of that side of the body on which they are inserted. For example, a fasciculus, let us say, of the right side arises dorso-laterally from the superficial external fascia. It courses obliquely backwards and downwards, and leaves the fascia to pass internal to the slime sacks. Median to the slime sacks it passes *internally* to the terminal portions of the fasciculi of the *left* side (being separated from the fascia by these), emerges on to the surface again at the mid-ventral line, and is now continued on the *left* side *over* the fasciculi of the latter side, separating them from the superficial fascia, into which it is inserted. Hence, in spite of the interdigitation, *all* the fasciculi arise and are inserted into the superficial external fascia. The anatomy of this portion of the obliquus is illustrated in fig. 10, which shows posteriorly two fasciculi on each side dissected clear of the overlapping fasciculi, so as to expose the whole of their course. Anteriorly the overlapping portions are wider and closer knit, and the first few fasciculi on each side are usually wider than the remainder. Omitting the very small posterior fasciculi, which are difficult to delimit, there are about 100 on each side.

Behind the heart (fig. 5) the obliquus covers superficially the ventral half or belly surface of the body. Hence its dorsal abdominal border is roughly coincident with the roof of the body cavity. Its fibres pass downwards and backwards in a slight curve, and above the line of the slime sacks it covers externally the ventral portion of the M. parietalis, whilst the slime sacks themselves in the relaxed condition lie in depressions on its outer surface. Ventrally it covers externally the M. rectus, and between the ventral border of the parietalis and the dorsal border of the rectus it forms the only muscular wall of the abdominal cavity (fig. 1). Behind the cloaca it has no appreciable existence.* The fibres of the superficial external fascia, which everywhere covers the obliquus, course in a direction *opposite* to that of the fibres of the muscle.

The function of the obliquus is to powerfully compress the walls of the body. In the region of the body in front of the gill apertures this compression, owing to the interdigitation of the fasciculi ventrally, is by far the most powerful. This is very obvious when watching a living animal, when one sees how the branchial region of the body is, as it were, wrung dry like a sponge. Another important function of the obliquus is to express the pre-cloacal slime sacks, which have no intrinsic musculature.† When the obliquus is relaxed the expanded slime sacks lie in depressions on its surface, so that when the muscle contracts they are driven against the skin, which here closely investing them and having little give, they are flattened between the obliquus and the skin.

* But cp. the description of the sphincter cloacæ and the transversus caudalis.

† J. Müller states, however, that in *Bdellostoma* each slime sack is surrounded by a special muscular membrane.

In *Bdellostoma*, according to J. MÜLLER, the anterior extremity of the obliquus is considerably narrowed down, and is not a blunt dorsal expansion as in *Myxine*. MÜLLER was the first to point out that there is a very striking difference between *Bdellostoma* and *Myxine*, since in the former the obliquus passes *external* to the slime sacks, the apertures of which open between the muscle fibres. Here, too, the compressing action of the obliquus affects the slime sacks, but of course in a different way.

32. *M. rectus.* (Figs. 1, 3, 5, 9, 11, *rect.*).

J. MÜLLER, *Gerade Bauchmuskel* (p. 247).
P. FÜRBRINGER and WIEDERSHEIM, *M. rectus abdominis* (p. 89 and p. 233).
M. FÜRBRINGER, *M. rectus* (pp. 614 and 628). *Hypobranchiale Musculatur* (p. 627).

I have adopted MAX FÜRBRINGER'S term for this muscle, as being less misleading than his brother's. The two recti are covered throughout by the obliqui, and for the greater part of their course they lie roughly between the two rows of slime sacks (fig. 1). They arose in the specimen now described (26 cm.) 7 mm. in front of the cloaca by elongated spindle-shaped muscular strands, connected by slender fibro-muscular cords with the narrowed anterior end of the strong sphincter cloacæ. These strands soon shorten and thicken to form the paired series of (generally) alternating myomeres which constitute the rectus muscle. Throughout the entire abdomen, however, the myomeres are of a transversely wide irregular shape, are separated by extensive ligamenta intermuscularia (inscriptiones tendineæ), and, as at the remainder of their course, are in contact at the mid-ventral line. Abdominally, the rectus is in fact more or less rudimentary, and forms the mid-ventral boundary of the body cavity. It narrows down to pass between the branchial orifices, but in front of the latter at once begins to gradually increase in width and strength, until in the present specimen it was widest at about 11 mm. behind its anterior extremity. In front of its widest part it rapidly flattens from side to side into a *vertical* ribbon, which creeps between the median and lateral heads of the copulo-glossus profundus, to be inserted (usually) by a very short ligament into the sheath of the posterior extremity of the middle segment of the basal plate (near its junction with the posterior segment) at about the middle of its ventro-lateral surface.

The segmentation of the rectus may be tabularised as follows (26 cm. Hag):—

	Right Side.		Left Side.	
	Myomeres of Parietalis.	Myomeres of Rectus.	Myomeres of Rectus.	Myomeres of Parietalis.
In front of Branchial Apertures	22	19	21	22
Opposite Branchial Apertures	1	1	1	1
Between Branchial Apertures and Cloaca . .	50	52	56	55
Total .	73	72	78	78

There is thus a close agreement in *total* number between the two segmented muscles even when the numbers of the two sides do not agree, and this agreement also extends in general to the ligamenta intermuscularia. Therefore, as the myomeres of the rectus are generally opposite those of the parietalis, the former may conceivably represent the disassociated ventral portions of the latter. Hence the myomeres of the parietalis should (and do) alternate. These statements, however, do not apply to the whole length of the rectus in every specimen, as the two sides may in parts agree or alternate with the parietalis in the same individual. The latter condition is shown in fig. 5.

These discrepancies are to be expected, since the state of contraction of the muscle will necessarily affect its position. J. MÜLLER also favours the view of the complete correspondence of the myomeres of the rectus and parietalis, and states further that these two muscles are *completely* interrupted by the row of slime sacks in *Bdellostoma*. The latter cannot be said to apply to *Myxine* (fig. 1); and if it did, its significance would be neutralised by the fact that the presence of the slime sacks has not affected the obliquus, lying *between* the rectus + parietalis and the slime sacks. Further, according to J. MÜLLER, the myomeres of the two recti are *symmetrical*; and as the myotomes of *Bdellostoma* alternate, according to AYERS and JACKSON (although this is not as easy to determine as one would imagine), this should not be the case. WIEDERSHEIM correctly states that the myomeres of the rectus alternate in *Myxine*, and assumes that this muscle represents a detached portion of the parietalis. M. FÜRBRINGER seems to favour the same view, but draws attention to a certain asymmetry between the two muscles, *i.e.* there are fewer hypobranchial (rectus) than epibranchial (parietalis) myomeres. This I also find. The whole question, however, has been reopened by the work of WIKSTRÖM,* and must therefore be left over until the nerves are considered.

The rectus clearly performs a double function. In the abdomen it assists in flexing the body ventrally, but owing to its feeble development at this region its action cannot be powerful, whilst its stronger anterior portion assists in the retraction of the basal plate, that is, when the extension of the body is preserved by the parietalis.

Ammocœtes and *Petromyzon* also have an anterior representative of the rectus, as first pointed out by A. SCHNEIDER.†

Since writing the above I have dissected a 45½ cm. Hag in which the rectus was inserted, not into the basal plate, but into the external fascia of the copulo-glossus profundus. The two heads of the latter muscle diverged as usual to admit the passage of the rectus, but it terminated abruptly on both sides 14 mm. behind this place. This very interesting variation seems to emphasise the vestigial (or rudimentary?) nature of this muscle.

* *Anat. Anz.*, xiii. p. 401, 1897. He concludes from the innervation that the two muscles are *not* homologous, segment for segment.

† *Zool. Anz.*, v. p. 164, 1882.

33. Geography of the Preceding Muscles.

I include here two tables indicating the longitudinal extent of the muscles in my large series of sections on both sides of the body. These tables will be useful in subsequent sections of the work, especially those on the blood-vessels and nerves, so that when a structure is being followed forwards or backwards in the charts it can be seen by a glance at the tables what muscular region of the body is being traversed. I have excluded the tendons, when present, and hence the figures only relate to the belly of the muscles. R = right, L = left.

From Before Backwards.

R. 7–371, L. 27–377 } Copulo-tentaculo-coronarius (F.J.C.).

R. 12–142, L. 27–164 } Transversus oris.

R. 30–73, L. 35–85 } Ethmoideo-nasalis.

R. 44–146, L. 51–157 } Tentaculo-ethmoidalis.

R. 51–481, L. 77–503 } Tentacularis posterior.

R. 63–375, L. 72–381 } Nasalis.

R. 79 { 226 External Head, 266 Internal Head
L. 86 { 250 External Head, 278 Internal Head } Copulo-ethmoidalis.

R. 118–184, L. 128–203 } Coronarius (F.J.C.).

R. 122–441, L. 126–450 } Palato-ethmoidalis superficialis.

R. 123–371, L. 151–377 } Copulo-tentaculo-coronarius (P.F., minus the coronarius, however).

R. 142–315, L. 144–319 } Palato-ethmoidalis profundus.

R. 201–423, L. 222–430 } Copulo-palatinus.

R. 222 —, L. 249 — } Obliquus.

R. 273–739, L. 289–757 } Hyo-copulo-palatinus.

R. 287–721, L. 297–734 } Copulo-quadratus profundus.

R. 292–478 External and Internal Heads
L. 301 { 498 External Head, 485 Internal Head } Palato-coronarius.

R. 303 —, L. 322 — } Parietalis (from first myotome).

R. 346–1021, L. 359–1014 } Copulo-glossus superficialis.

350 { R { 1214 Median Head, 1445 Lateral Head
L { 1210 Median Head, 1474 Lateral Head } Copulo-glossus profundus.

R. 386–599 / L. 410–632 } Quadrato-palatinus.
R. 465–740 / L. 475–757 } Velo-quadratus.
R. 467 — / L. 474 — } Parietalis (from dorsal cranial portion).
R. 483–723 / L. 489–745 } Hyo-copulo-glossus.
R. 557–1081 / L. 590–1087 } Copulo-quadratus superficialis.
R. 616–784 / L. 639–787 } Velo-spinalis.
R. 668–727 / L. 690–777 } Cranio-hyoideus.
R. 675 — / L. 681 — } Rectus.
R. 694–2490 / L. 703–2400 } Constrictor pharyngis.
R. 854–2089 / L. 852–2090 } Copulo-copularis.
R. 1113–2267 / L. 1078–2287 } Longitudinalis linguæ.
1944–2291 Perpendicularis.
R. 2371 / L. 2094 } 3304 Constrictor branchiarum et cardiæ.

From Behind Forwards.

R. — 467 / L. — 474 } Parietalis (to dorsal cranial portion).
R. — 303 / L. — 322 } Parietalis (to first myotome).
R. — 222 / L. — 249 } Obliquus.
R. — 675 / L. — 681 } Rectus.
3304 < R. 2371 / L. 2094 } Constrictor branchiarum et cardiæ.
R. 2490–694 / L. 2400–703 } Constrictor pharyngis.
2291–1944 Perpendicularis.
R. 2267–1113 / L. 2287–1078 } Longitudinalis linguæ.
R. 2089–854 / L. 2090–852 } Copulo-copularis.
R. { 1214 Median Head / 1445 Lateral Head }
L. { 1210 Median Head / 1474 Lateral Head } 350 Copulo-glossus profundus.
R. 1081–557 / L. 1087–590 } Copulo-quadratus superficialis.
R. 1021–346 / L. 1014–359 } Copulo-glossus superficialis.
R. 784–616 / L. 787–639 } Velo-spinalis.
R. 727–668 / L. 777–690 } Cranio-hyoideus.

R. 740–465 } Velo-quadratus.
L. 757–475 }

R. 739–273 } Hyo-copulo-palatinus.
L. 757–289 }

R. 723–483 } Hyo-copulo-glossus.
L. 745–489 }

R. 721–287 } Copulo-quadratus profundus.
L. 734–297 }

R. 599–386 } Quadrato-palatinus.
L. 632–410 }

R. 481–51 } Tentacularis posterior.
L. 503–77 }

R. 478 External and Internal Heads–292 }
L. { 498 External Head } . . 301 } Palato-coronarius.
{ 485 Internal Head }

R. 441–122 } Palato-ethmoidalis superficialis.
L. 450–126 }

R. 423–201 } Copulo-palatinus.
L. 430–222 }

R. 375–63 } Nasalis.
L. 381–72 }

R. 371–123 } Copulo-tentaculo-coronarius (P.F., minus the coronarius, however).
L. 377–151 }

R. 371–7 } Copulo-tentaculo-coronarius (F.J.C.).
L. 377–27 }

R. 315–142 } Palato-ethmoidalis profundus.
L. 319–144 }

R. { 226 External Head } 79 }
{ 266 Internal Head } } Copulo-ethmoidalis.
L. { 250 External Head } 86 }
{ 278 Internal Head }

R. 184–118 } Coronarius (F.J.C.).
L. 203–128 }

R. 142–12 } Transversus oris.
L. 164–27 }

R. 146–44 } Tentaculo-ethmoidalis.
L. 157–51 }

R. 73–30 } Ethmoideo-nasalis.
L. 85–35 }

34. *M. sphincter cloacæ.** F.J.C. (Fig. 4, *s. cl.*)

J. Müller, *Sphincter der Cloake* (*Ab. Ak. Berlin*, 1843, p. 167, 1845).

This muscle, in a 32 cm. Hag, surrounded the whole of the cloaca except the most postero-ventral 3 mm. When a Hag is pinned out on its back and the ventral skin removed, it is seen that the obliquus muscle extends (at least) as far backwards as the base of the cloacal elevation, and there ceases. The most posterior pre-cloacal fibres of this muscle, instead of meeting in a median ventral linea as elsewhere, bent forwards immediately in front of the cloaca, and were continued forwards external to the obliquus proper for 3 mm. in a 30 cm. Hag. When these are removed it is noticed that, behind, the ventral linea becomes indistinct, and there are indications of the

* Described from dissections only.

obliquus fibres crossing over the middle line on to their opposite side, as figured by J. MÜLLER in *Myxine*. This author, however, erroneously regards these fibres as belonging to the sphincter cloacæ. I assume that he is referring to the obliquus, and not to the sphincter, because he says that the fibres arise from the parietalis, and those of the sphincter, of course, do not. Further, the true sphincter is figured behind and distinct from them. On removal of the obliquus the sphincter cloacæ is exposed, and the rectum and cloaca may now be removed, with the sphincter intact and *in situ*. It is a powerful muscle, the origin of which occupied in the above Hag the 7 mm. in front of the cloacal aperture, and commenced just behind the posterior termination of the rectus. There is no question of crossing at the origin.

The fibres of the sphincter cloacæ arise at the mid-ventral line corresponding to the linea of the obliquus, and extend from the ventral wall of the rectum on to the descending ventral wall of the cloaca, but not over the whole of the latter, as above stated. From thence they pass as a compact mass at an obtuse angle backwards, outwards, and upwards in a curve round the lateral wall of the cloaca. Arriving at the dorso-posterior wall or roof of the cloaca, the anterior half of the fibres take a forward bend and pass over into those of the opposite side at right angles to the long axis of the gut, and there is hence (apparently) no mid-dorsal linea here. The fibres forming the posterior half, however, continue their backward course, and hence meet those of the other side at an angle. Consequently there is a mid-dorsal linea here, and there are indications that it is continued forwards throughout the entire extent of the muscle, although it is not obvious in dissection. The anterior three-quarters of the sphincter lie *external* to the terminal portions of the segmental ducts, so that the muscle will also act as a constrictor to these.

35. *M. transversus caudalis*, F.J.C.* (Fig. 4, *t. c.*)

SCHNEIDER, 17, p. 114.

I had thought that this muscle had hitherto escaped notice, but it is evidently the one briefly mentioned by SCHNEIDER.

The transversus caudalis is a long, irregular, very diffuse and ill-defined muscle, developed to take the place functionally of the obliquus behind the cloaca. It is in fact an extrinsic constrictor muscle of the post-cloacal slime sacks (which, like the others, have no intrinsic musculature), and has no existence apart from them. I include here the two slime sacks generally found *opposite* the cloacal *aperture*, since these are morphologically post-cloacal.

Anteriorly there are a few fasciculi (seven in the present case, fig. 4, *obl'*) which arise like the obliquus, but at a gradually descending level, from the superficial external fascia of the parietalis, and the largest and most anterior bundle is actually serially homologous with the obliquus. These bundles may therefore be said to represent the

* Described from dissections only.

most posterior section of the obliquus, the first of which passes *external* to the first post-cloacal slime sack (instead of internal to it, as in the pre-cloacal slime sacks), to meet at a mid-ventral linea over its anterior half. This course is the less surprising when we remember that in *Bdellostoma*, according to J. Müller, the obliquus *always* passes external to the slime sacks. In addition, however, to the above, the first pair of post-cloacal slime sacks have a complete set of constrictor fibres belonging to the transversus caudalis.

We may now dissect out the two rows of post-cloacal slime sacks intact, together with the transversus caudalis, and examine the muscle *in situ*. All the slime sacks except the first pair, which are symmetrical, and the second pair, which are somewhat asymmetrical,* alternate; and not only is this the case, but space is so limited that they actually interdigitate, and hence all the external apertures except the first pair strictly alternate. The two rows are bound together into one coherent whole by the transversus caudalis, which can thus act as a powerful constrictor to them. The muscle arises at an irregular, ill-defined dorsal linea, which zigzags from side to side, following the depression between the dovetailed slime sacks. Over the first two pairs of slime sacks, however, this linea is straight, and lies in the mid-dorsal position. From the dorsal linea the fibres generally pass more or less at right angles to the long axis round the lateral surfaces of the slime sacks, which (except the last three or four) are completely covered by them dorsally. The fibres continue their course round the sacks, and the two sides become continuous on the ventral surface, *i.e.* there is no ventral linea. They do not generally diverge to pass round the openings of the sacks, but many of them end on the sack itself just above the opening. Hence there are fewer fibres below the apertures than above them, although in places fresh fibres are formed below. The muscle is usually specially strong at the depression between the sacks, but, except in the case of the first pair, the fibres encircle *both* rows of sacks, and do not extend over the opposed surfaces, *i.e.* between them; and in fact the sacks are so closely packed together that there is no room. Hence there is only one constrictor for both rows, which must therefore be discharged simultaneously without the power of independent action. At the mid-ventral line the fibres diverge to allow the exit of the ventral "fin rays." Posteriorly some of the fibres, as they traverse the lateral surfaces of the sacks, pass forwards, whilst others course backwards, so that they cross at an angle.

36. *M. cordis caudalis.* (Figs. 4, 7, *cd. c.*)

G. Retzius, 15, p. 96.
Greene, 8, p. 367.

A curious small fan-shaped paired muscle, largely covered by the parietalis, the handle of the fan or insertion pointing straight forwards. It arises as follows:—(*a*) the dorsal fibres have a long origin from the skeletogenous layer of the notochord at the

* This is subject to variation.

angle formed by the junction of the latter with the median ventral bar of the caudal fin skeleton. This agrees with what I find in a series of sections I have made of the entire tail region, but in one dissection the dorsal fibres arose from the dorsal margin of the median ventral bar, and certainly did not reach the chorda. This is the condition figured; (*b*) posteriorly it has a diffuse origin from the entire width of the ventral bar —of course behind the region of the caudal heart; (*c*) the ventral fibres have a long origin from the lower margin of the ventral bar and from the roots of the anterior "fin rays" fusing with the bar—in one specimen from eleven of these, in the Hag figured from seven, but in the sections from two only, the heart and large vessels intervening between the muscle and the "fin rays" in front. This part of the origin is not mentioned by RETZIUS in *Myxine*, but it is present in *Bdellostoma*, according to GREENE.

From their origin the fibres rapidly concentrate, so that the muscle now passes straight forwards as a sharply converging belly, to terminate in a narrow insertion (immediately behind the last slime sack) into the external margin of the tranversely expanded extremity of the knob projecting from the anterior margin of the median ventral bar (cp. Part I., fig. 17). The entire length of the muscle in a 30 cm. Hag was 7 mm. and its greatest width 3 mm. In *Bdellostoma*, according to GREENE, the measurements were 6·3 mm. and 2·8 mm. As *Bdellostoma* is, of course, a much larger form than *Myxine*, it would seem that the muscle is not so well developed in the former genus.

The cordis caudalis muscles are crescent-shaped in transverse section, fitting over and passing external to the paired caudal hearts, each of which lies between one of the muscles and the median ventral bar. The caudal hearts possess no intrinsic musculature, but have only fibrous walls, as pointed out by G. RETZIUS and GREENE. In this respect the caudal heart differs from the portal heart, which is controlled by intrinsic musculature.

The fibres of the cordis caudalis are in marked contrast to those of the adjacent parietalis. They are striped, but have a *very small calibre*. This is not mentioned by GREENE. I refer to the character of these fibres in another part of this paper on the histology of the muscles.

The caudal hearts and their muscles were first discovered by G. RETZIUS, who briefly described them. I shall deal with the function of the muscle when I treat of the vascular system, but in the meantime I may quote the following statement by RETZIUS, based on observations of the living animal: "Bei jeder 'Systole' kehrte sich der Knopf der Knorpelplatte [the knob of the median ventral bar above] von links nach rechts, und dabei entleerten die beiden paarigen Hertzsäcke ihren Inhalt in die Caudalvene. Dann kehrte der Knopf wieder nach links zurück und blieb einen Moment stille; so kam eine neue Verschiebung nach rechts mit einer Ausleerung der Säcke u. s. w. Dabei waren deutlich die beiden seitlichen platten Muskeln die Motoren, welche gleichzeitig auf die Wände der Hertzsäcke drücken und den Inhalt vorwärts verschieben." This account differs from that given by GREENE of *Bdellostoma*, and it is quite

evident from a mere examination of RETZIUS' statement that if both hearts are to discharge simultaneously, there cannot be any lateral movement of the anterior knob. GREENE's description in fact applies also to *Myxine*.

Perhaps I may here make a preliminary announcement on another question discussed by RETZIUS in the above paper. This is as to whether the caudal hearts transmit blood from the large subcutaneous space to the veins. RETZIUS concludes, on evidence communicated to him by KLINCKOWSTRÖM, that it does, and this has since been amply confirmed both by the latter and by GREENE.* In studying the question from a new point of view, *i.e.* by serial sections, it is easy to demonstrate beyond all question that the caudal hearts *are* in communication with the subcutaneous sinus. The question now arises—How does the blood enter the latter sinus? Beyond RETZIUS, who simply mentions the matter, only KLINCKOWSTRÖM has touched on this point. I may therefore mention that there are further communications *anteriorly* between the sinus and the large internal vascular cavities of the snout which provide ample opportunity for the entrance of blood into the subcutaneous sinus. In this connection the reader may refer to my description of the communications between the afferent branchial vessels and the pleural sacks (5, p. 325).

LITERATURE.

[In this list only those works are included which contain original observations on the muscles of Myxinoids.]

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* Cp. also FAVARO's recent note.

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EXPLANATION OF PLATES.

Reference Letters.*

a. c. m. Middle cutaneous artery.
a. c. s. Superior cutaneous artery.
a. sp. Spinalis artery, splitting into superior and inferior spinal arteries.
a. v. c. i. Inferior cutaneous artery and vein.
a. v. d. Dorsalis artery and vein.
a. v. v. Ventralis artery and vein.
c. ao. Cardiac aorta.
c. b. c. Branchial portion
c. b. c′. Paired anterior limb
c. b. c″. Cardiac portion
} of the M. constrictor branchiarum et cardiæ.
The numerals (*1–14*) indicate the regions of the muscle referred to in the text (*q.v.*).
cd. c. M. cordis caudalis.
c. e. External head
c. e′. Internal head
c. e″. Fused external and internal heads
} of the M. copulo-ethmoidalis.
c. g. p′. Lateral head
c. g. p″. Median head
} of the M. copulo-glossus profundus.
c. g. s. M. copulo-glossus superficialis.
c. g. s′. Median slip of tendon of above to ventral skin.
c. g. s″. Lateral slip of tendon of above to base of fourth tentacle. Between these two slips the intermediate portion of the tendon is bending round into the mouth.
c. h. M. cranio-hyoideus.
c. i. R. cutaneus inferior of the spinal nerve.
c. m. R. cutaneus medius of the spinal nerve.
c. o. M. coronarius.
c. p′. First division
c. p″. Second division
c. p‴. Third division
} of the M. constrictor pharyngis.
cp. c. M. copulo-copularis.
c. pl. M. copulo-palatinus.
cp. t. c. First or principal head
cp. t. c′. Posterior division
cp. t. c″. Anterior division (= Tentacularis anterior of P. Fürbringer)
} of the M. copulo-tentaculo-coronarius.
c. q. p. M. copulo-quadratus profundus.
c. q. s. M. copulo-quadratus superficialis.
c. sp. R. cutaneus superior of the spinal nerve.
d. m. b. Dorsal motor branch of the ventral root of the spinal nerve.
d. r. Dorsal root and ganglion of the spinal nerve. Above, it gives off the dorsal sensory branch, and below, the ventral sensory branch.
e. Vestigial eye.
e. n. M. ethmoideo-nasalis.
f. r. The ventral "fin rays" of the caudal fin (those at posterior extremity removed).
h. c. g. M. hyo-copulo-glossus.
h. c. p. M. hyo-copulo-palatinus.
i. c. b. Inferior chondroidal bar.
l. lg. M. longitudinalis linguæ.
l. p. c. Large left posterior cardinal vein, connected with the small right one by an inflated anastomosis.
m. Mucosa enveloping dental apparatus.

* Care has been taken throughout this work not to use the same letters for different structures. Hence any letters used in the present Part but not explained in this list will be found in the list given in Part I., pp. 786-7.

mes. Median dorsal mesentery transmitting a genito-mesenteric artery.
nas. M. nasalis.
obl. M. obliquus.
obl'. Terminal post-cloacal section of the M. obliquus.
ov. Ovarian portion of the hermaphrodite gonad.
par. M. parietalis (forming the myotomes).
p. e. p. M. palato-ethmoidalis profundus.
p. e. s. M. palato-ethmoidalis superficialis.
pl. c. External head of the M. palato-coronarius.
pp. M. perpendicularis.
pt. Peritoneum.
p. v. Portal vein, receiving vessels from the gut and the gonad.
q. p. M. quadrato-palatinus.
r. d. R. dorsalis of the spinal nerve.
rect. M. rectus.
r. v. R. ventralis of the spinal nerve.
s. ao. Systemic aorta.
sc. b. s. Subcutaneous blood sinus.
s. cl. M. sphincter cloacæ.
s. d. Segmental duct. On the right side is shown a Malpighian body opening into it, with its arterial and venous supply.
s. s. Slime sack. On the right side of fig. 1 is shown a duct and its aperture.
s. s'. Depressions on the M. obliquus seen on removal of the slime sacks.
sy. Sympathetic nerve or R. intestinalis, formed by the fusion of the two visceral branches of the vagus.
t. c. M. transversus caudalis.
t. e. M. tentaculo-ethmoidalis.
t. o. M. transversus oris.
t. p. M. tentacularis posterior.
v. c. m. s. Middle and superior cutaneous vein.
v. q. Ventral division
v. q'. Middle division } of the M. velo-quadratus.
v. q''. Dorsal division
v. r. Ventral root of the spinal nerve formed by the fusion of four rootlets.
v. s. M. velo-spinalis.
v. sp. Spinalis vein formed by the union of superior and inferior spinal veins.

Plate I.

Fig. 1. Diagram illustrating the anatomy of a typical body segment of *Myxine*, reconstructed from various series of sections. Although all the structures which may occur in one segment have been projected into the same plane, the relative positions of the same are correctly indicated as found in a 19·5 cm. Hag. On the left side the distribution of a spinal nerve is shown in black, and on the right side the course of a segmental artery and vein in red and blue. On the right side the subcutaneous space, otherwise continuous round the body, is interrupted by the opening of the slime gland. It must be understood that the diagram epitomises the possibilities of a segment, and not the actual structure of *every* somite.

Plate II.

Fig. 2. Reconstruction from the large series of sections of the 25 cm. Hag of the M. constrictor branchiarum et cardiæ of the left side. × 11. The muscle is coloured red and its lacunæ black. The shape of the third gill is somewhat distorted, owing to the fact that the specimen had to be cut into three pieces in order to get it into the microtome, and one break was through the third gill. When the tissues are cut before embedding some swell more than others and project beyond the cut surface, and this disturbs the enumeration of the sections. For the explanation of the numbers, refer to the description of the muscle based on the sections in the text.

Fig. 3. Dissection from the left side of a 34½ cm. Hag, to illustrate the superficial anatomy of the muscles of the head and branchial region. × 3. The following structures have been removed: M. tentacularis posterior; the myotomes (except dorsally in front of the gill region); M. rectus (except insertion and a detached portion at the level of the first gill); M. obliquus; greater portion of the continuous external posterior sheet of the M. constrictor branchiarum et cardiæ; efferent gill ducts and the ductus œsophago-cutaneus (position of latter indicated by its constrictor—*14*); heart and left anterior cardinal and inferior jugular veins. Tentacles 3 and 4 cut off. Tentacles, gill sacks, and the regions of the M. constrictor branchiarum et cardiæ indicated by numerals (cp. text). Soft cartilage, blue; hard cartilage, red. Arteries, red and cross-striated; nerves, black.

Fig. 4. Lateral dissection of the left side of the tail of a 32 cm. Hag. × 3. Last two pre-cloacal slime sacks removed. Dorsal and postero-ventral "fin rays" cut away. Obliquus and parietalis cut away ventrally—the latter behind the last slime sack only to expose the M. cordis caudalis. Myotomes and post-cloacal slime sacks numbered from before backwards.

Fig. 5. Dissection from the left side of a 36 cm. Hag, to illustrate the musculature of the body taken at about the middle of the abdominal region. Perenyi fixation. × 2. A = anterior, D = dorsal. In front, the M. obliquus and the slime sacks have been removed; in the middle, the slime sacks only (leaving depressions behind); whilst posteriorly the figure represents the surface of the body as seen after removal of the skin.

Plate III.

Fig. 6. Broken series of transverse sections of the M. longitudinalis linguæ and its tendon, selected from the large series of a 25 cm. Hag, to illustrate the formation and fate of the tendon. Muscular tissue, red; tendinous portions, black; soft pseudo-cartilage, dotted; fibrous connective tissue, shaded. The figures refer to the numbers of the sections; and for the lettering cp. the description of the tendon of the M. longitudinalis linguæ in the text. In 720, two small nerves are shown dorsally cut in transverse section; and in 625, a portion of the median ventral channel formed by the mucosa of the mouth appears dorsally. All the sections were drawn with Edinger's projection apparatus to the same scale, and are × 26.

Fig. 7. Transverse sections of muscle fibres, all taken from one 31 cm. Hag, fixed in formol + alcohol, and all drawn to the same scale, in order to illustrate the differences in size. Stained with Mann's methyl-blue-eosin. Zeiss apochr. 1·5 mm., apert. 1·30, compens. oc. 4.

(*a*) Aplasmic fibre from the M. parietalis at about the middle of the back.
(*b*) Plasmic fibre of ditto from the same region.
(*c*) Medium-sized plasmic fibre from M. cordis caudalis.
(*d*) Plasmic fibre from the dorsal division of the M. velo-quadratus.
(*e*) Plasmic fibre from the M. velo-spinalis.
(*1*) Contractile elements (sarcostyles or fibrils?); (*2*) narrow elongated nuclei seen in transverse section (generally central, and characteristic of the aplasmic fibres); (3) peripheral zone of sarcoplasm of the plasmic fibres; (*4*) peripheral round or oval nuclei of the plasmic fibres; (5) peripheral blood capillaries of the plasmic fibres.

Plate IV.

Fig. 8. Superficial muscles of the dorsal surface of the head of a 25 cm. Hag, as seen after removal of the skin. Perenyi fixation. × 3. The anterior lobes of the brain are seen showing through the membranous brain case in front of the second myotome. The small first myotome is not shown in the figure, being covered, as well as the ventral portion of the second, by the dorsal extension of the M. obliquus. Note the alternation of the myotomes of the two sides. The numbers indicate the identity of the tentacles and the myotomes.

Fig. 9. Superficial muscles of the left lateral surface of the head of a 30 cm. Hag, after removal of the skin. Perenyi fixation. × 3. The dots indicate the line of insertion of the M. obliquus of the left side, whilst the dashes mark the line of origin of the corresponding muscle of the right side, both of which have been completely removed. The position of the first slime sack over the seventh myotome is shown by the dotted outline. Tentacles and myotomes numbered from before backwards.

Fig. 10. Superficial muscles of the ventral surface of the head of a 31 cm. Hag, after removal of the skin. Perenyi fixation. × 3. The lateral portion of the M. obliquus is foreshortened by the perspective. The fourth tentacle is displayed to illustrate its shape. Tentacles and myotomes numbered from before backwards.

Fig. 11. Same dissection and magnification as fig. 3 (*q.v.*), but with the following additional muscles removed:—copulo-quadratus superficialis, copulo-quadratus profundus, copulo-glossus superficialis, lateral head of the copulo-glossus profundus, copulo-palatinus, hyo-copulo-palatinus, and the palato-ethmoidalis superficialis. Hard cartilage, red; soft cartilage, blue; hard pseudo-cartilage, blue dotted; soft pseudo-cartilage, obliquely striated. Tentacles numbered from before backwards.

Fig. 12. Dissection of the roof of the mouth of a 31½ cm. Hag, to expose the skeleton and muscles of the pharyngeal velum. × 4. Mucosa, M. quadrato-palatinus, and both heads of the M. palato-coronarius removed. The figure gives a ventral view of the structures shown. Hard cartilage, red; soft cartilage, blue.

Fig. 13. Dissection from the left side of a 32½ cm. Hag, to illustrate the superficial anatomy of the posterior portion of the M. constrictor branchiarum et cardiæ. × 4. The body-wall, the efferent gill ducts (so far as seen), cardiac corta, left anterior cardinal vein, inferior jugular vein, and vagus nerve have been removed, whilst the definite ventral muscle bundles have been cut off short. The ligamentous sheet attaching the ventral border to the body-wall is not shown. This figure should be compared with figs. 2 and 3. For explanation of the numerals, cp. text.

Fig. 14. Lateral dissection from the right side of a 34 cm. Hag, to illustrate the relations of an intermuscular septum, as found at about the middle of the body. × 3. The specimen was macerated, and the muscle fibres picked off and brushed away. A = anterior, and D = dorsal. The numbers indicate the parts of the septum from above downwards (see text).

Mr F. J. Cole on the Morphology of Myxine. —— Part II, Plate I.

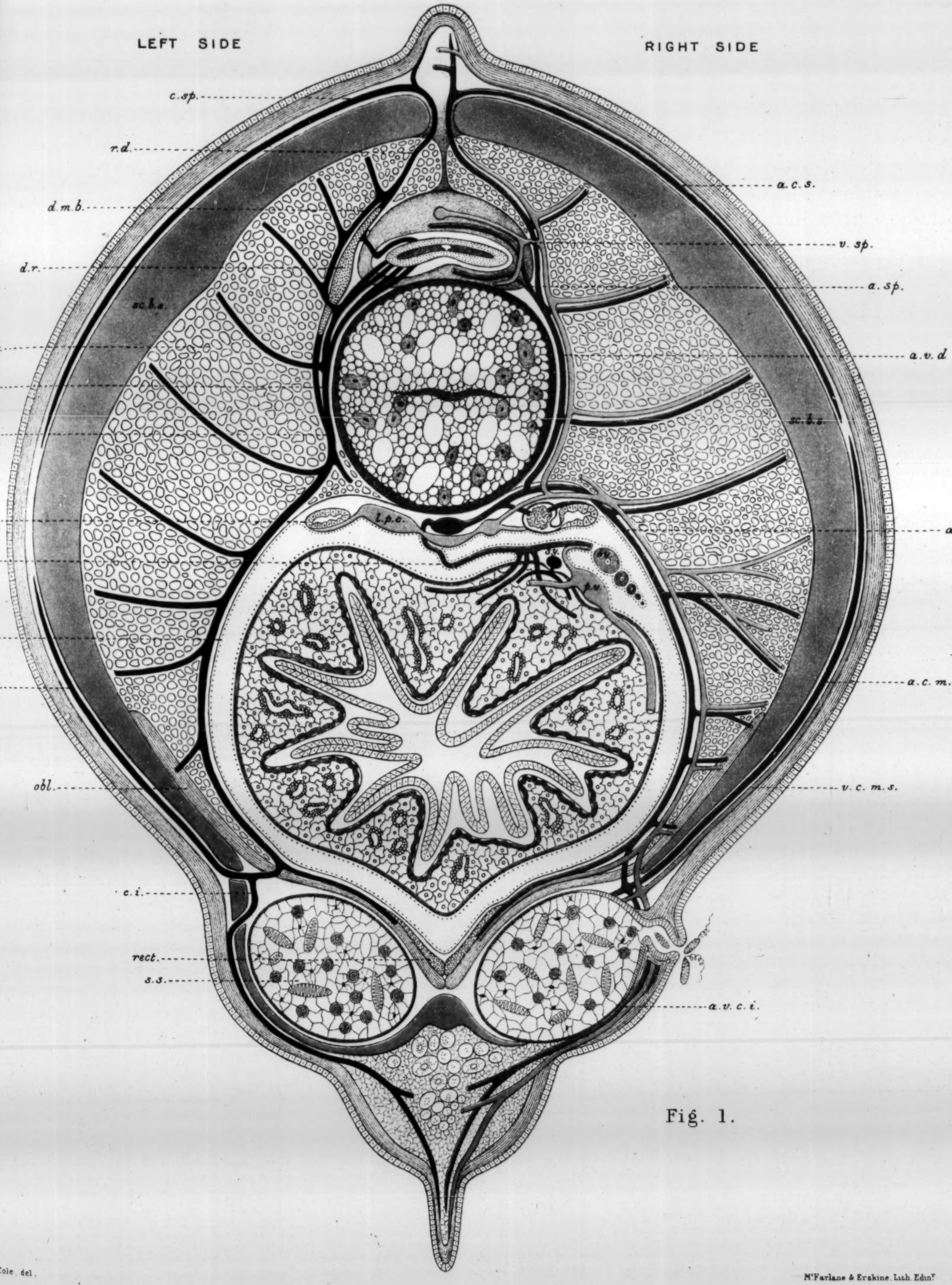

Fig. 1.

F.J. Cole. del.

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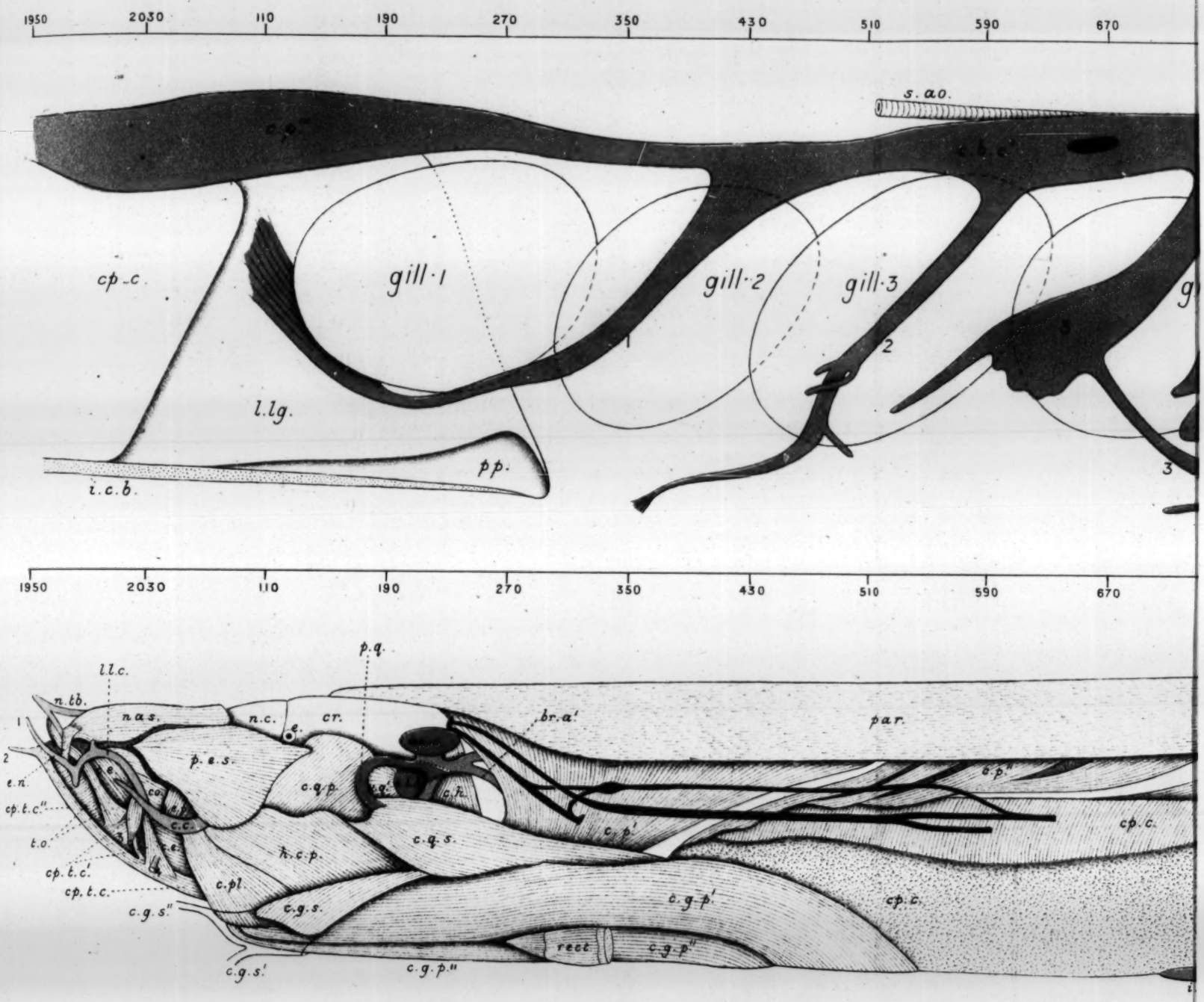


Fig. 3. × 3.

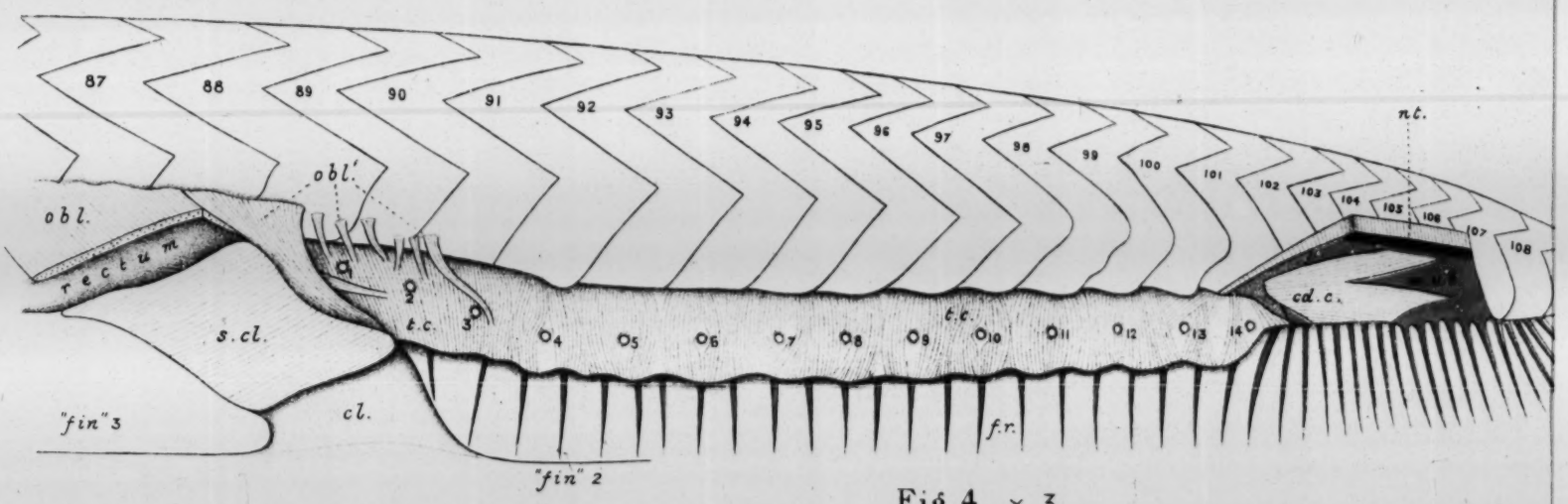


Fig. 4. × 3.

F. J. Cole, del.

PLATE II.

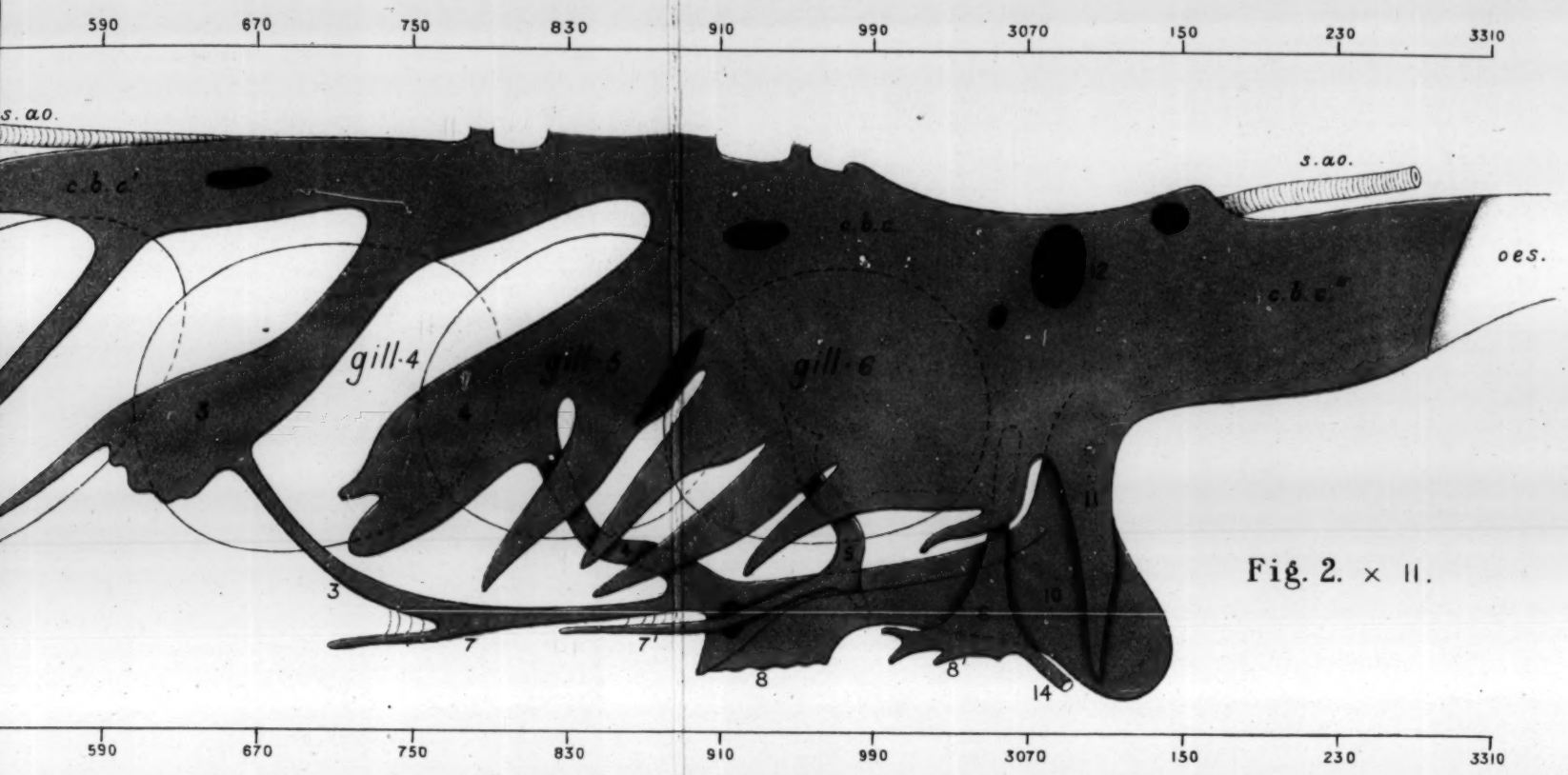
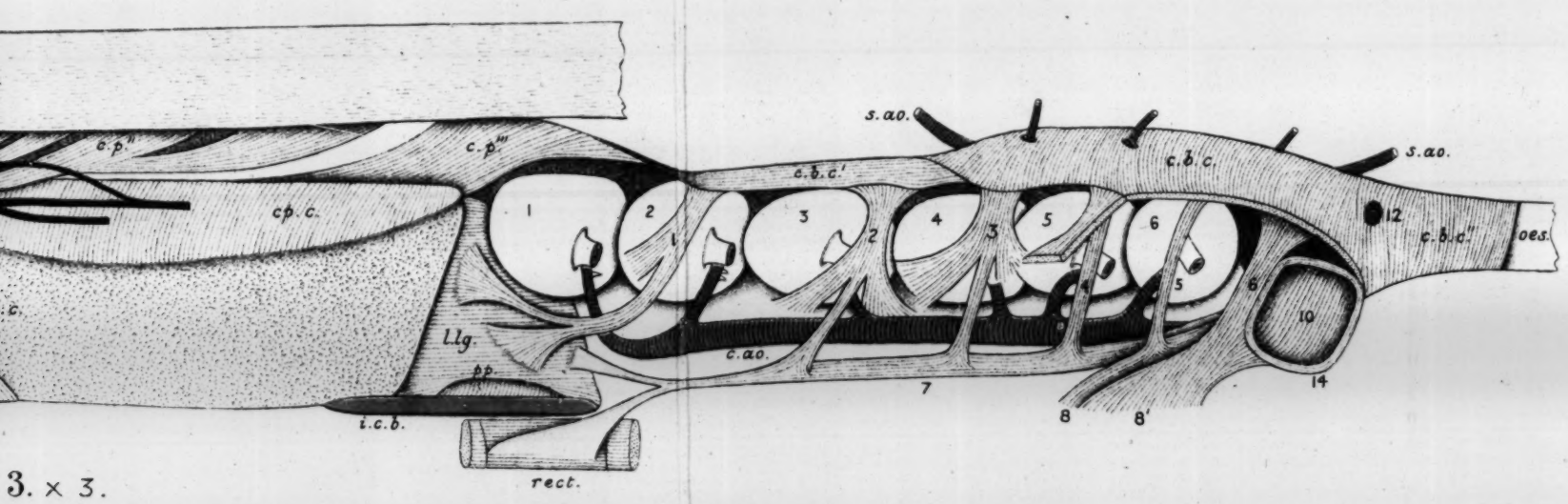
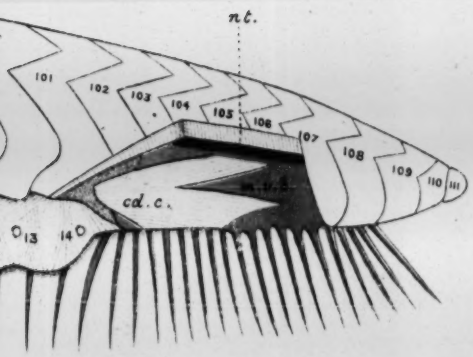


Fig. 2. × 11.



3. × 3.



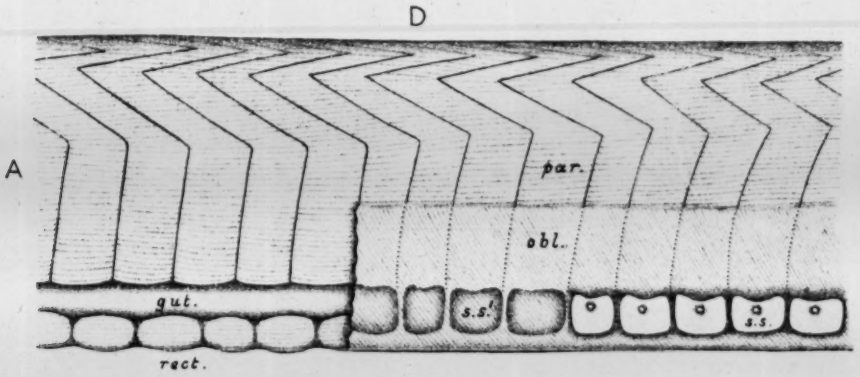


Fig. 5. × 2.

M'Farlane & Erskine Lith Edin'

Mr F. J. Cole on the Morphology of Myxine. — Part II. Plate III

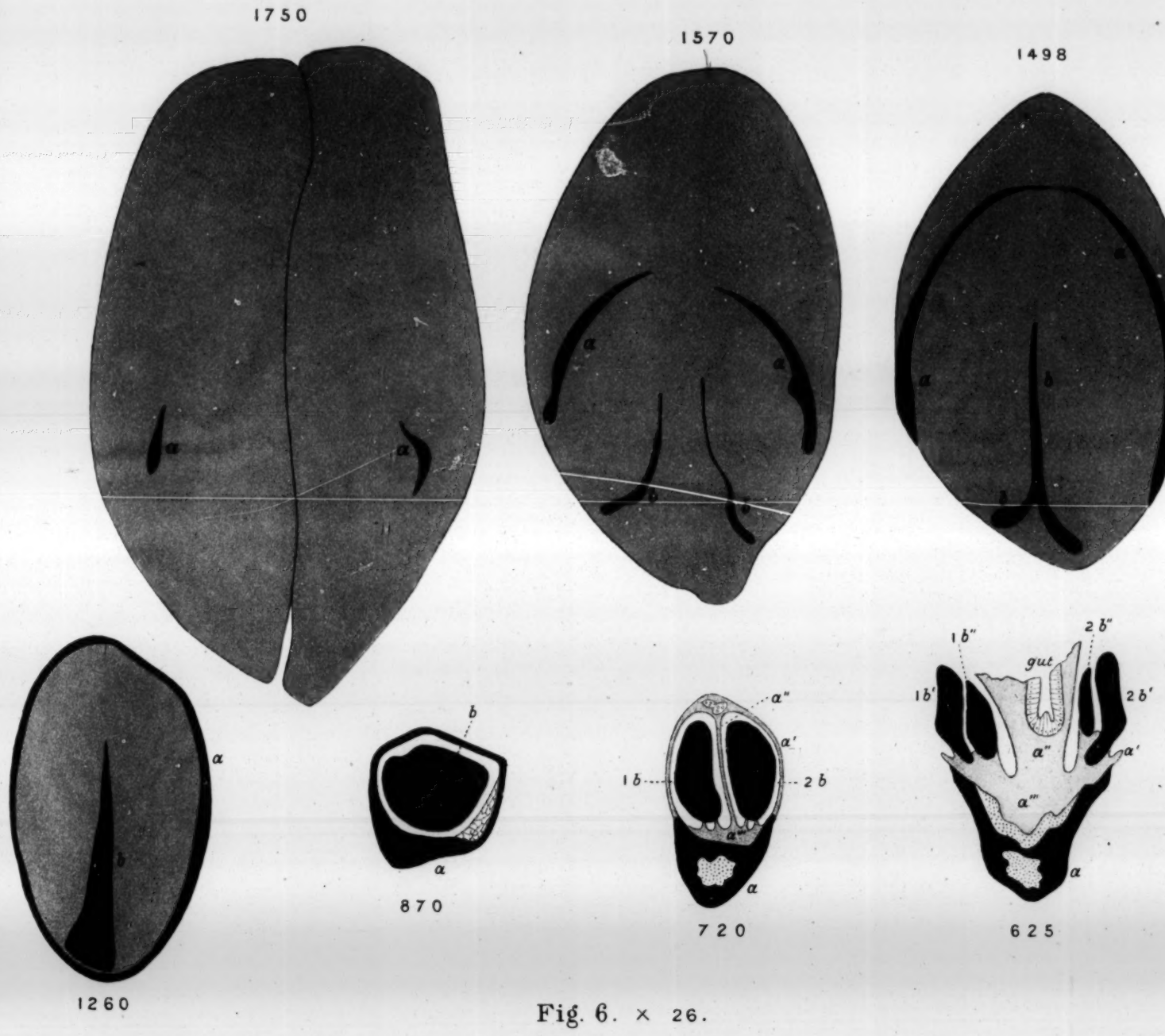


Fig. 6. × 26.

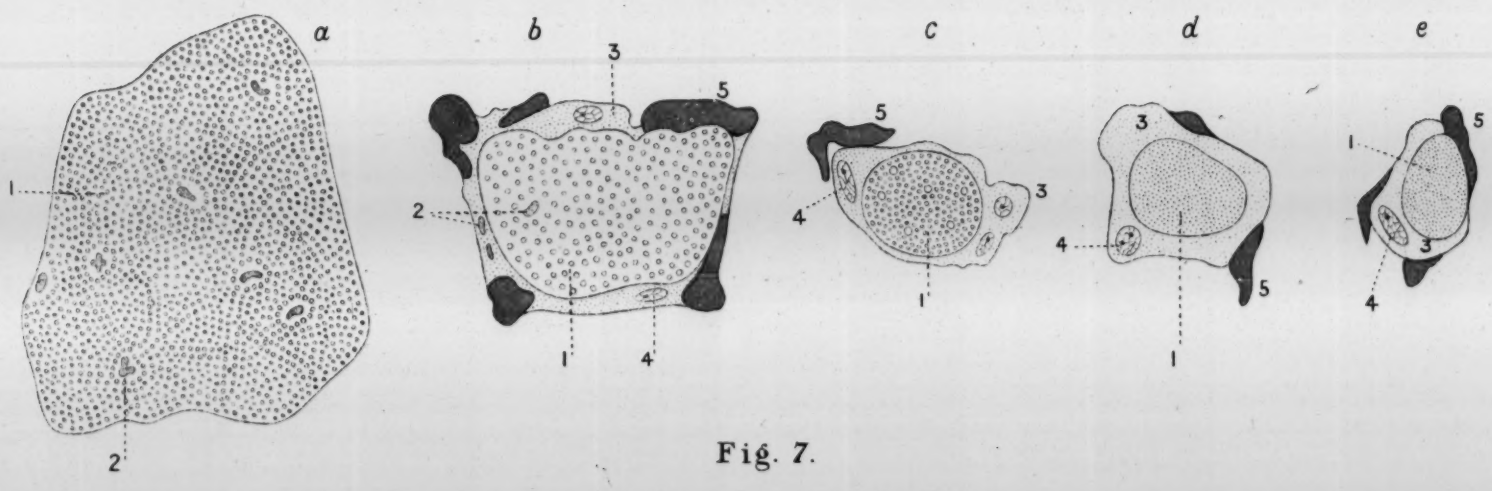


Fig. 7.

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Mr F. J. Cole on the Morphology of Myxine. — Part II. Plate IV.

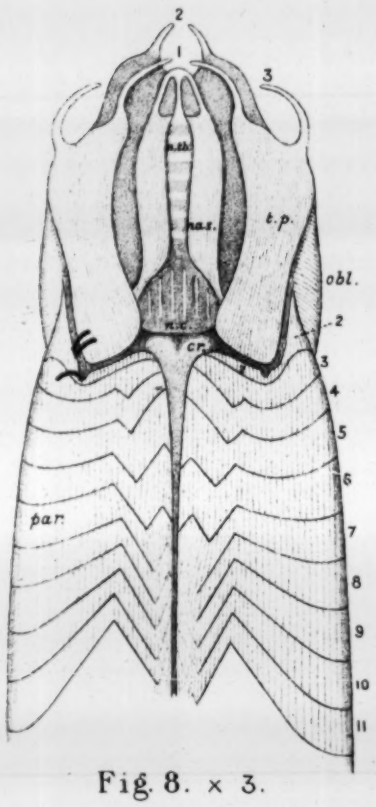


Fig. 8. × 3.

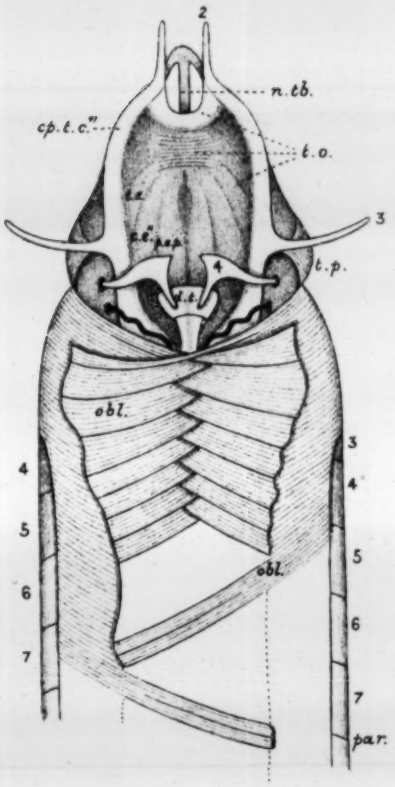


Fig. 10. × 3.

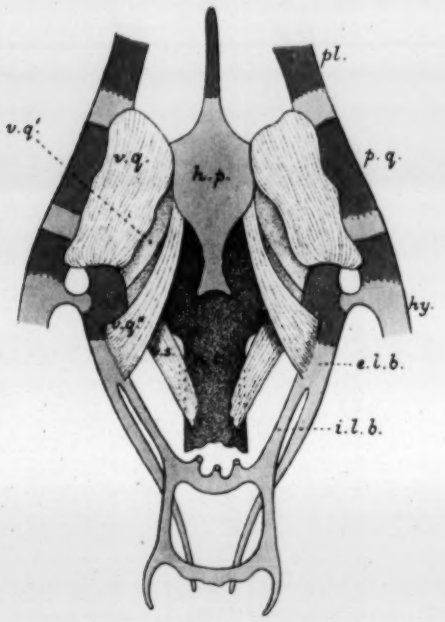
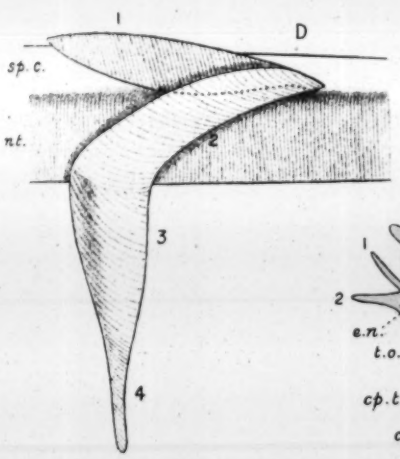


Fig. 12. × 4.



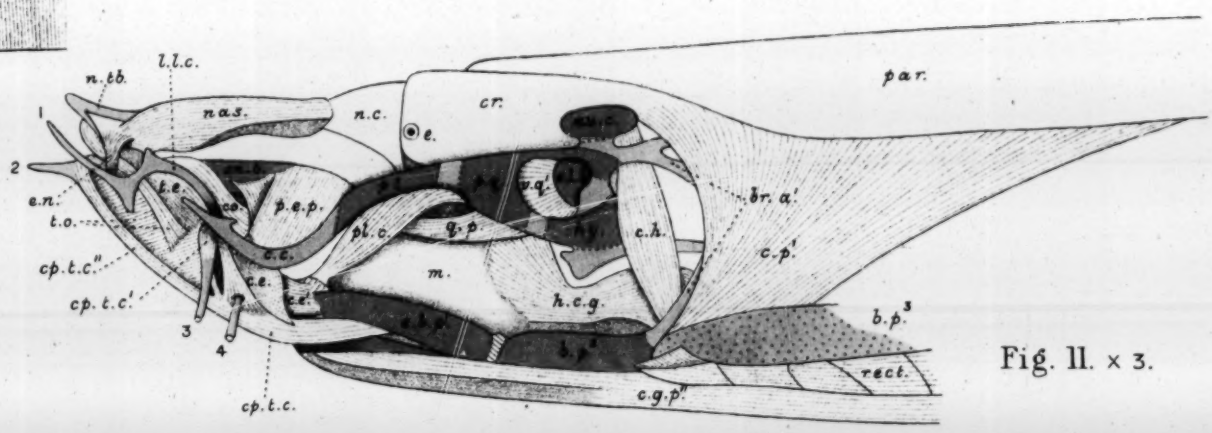


Fig. 14. × 3.

Fig. 11. × 3.

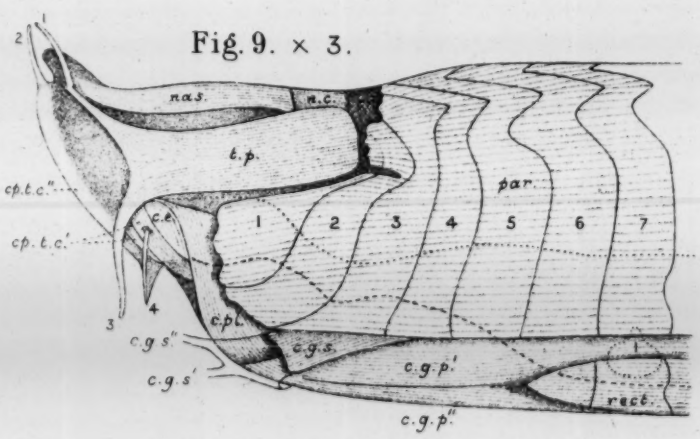


Fig. 9. × 3.

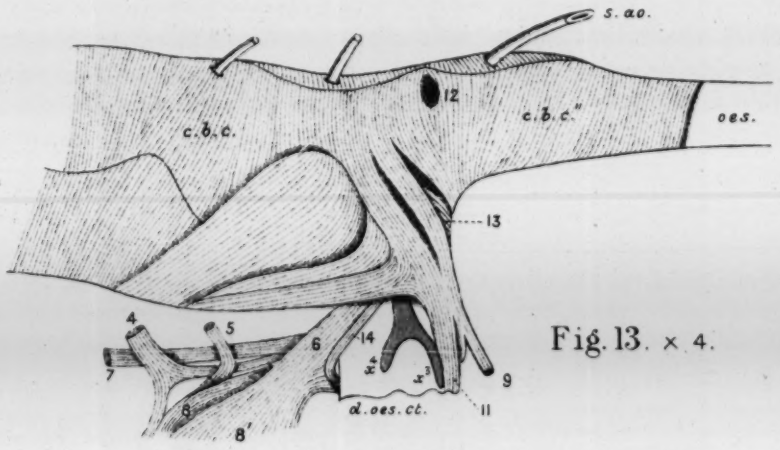


Fig. 13. × 4.

F. J. Cole. del

M.cFarlane & Erskine. Lith Edin.r

XXVII.—On the Fossil Osmundaceæ.

By **R. Kidston**, F.R.S. L. & E., F.G.S., Foreign Mem. K. Mineral. Gesell. zu St Petersburg; and **D. T. Gwynne-Vaughan**, M.A., Lecturer in Botany at Queen Margaret College, Glasgow University. (Plates I.–VI.)

(MS. received November 16, 1906. Read February 4, 1907. Issued separately July 5, 1907.)

PART I.

The two new species of *Osmundites* described in this paper are based upon two fossils from the Jurassic rocks near Gore, Otago district, New Zealand. The one was discovered by Mr Robert Dunlop, and the other by Mr Robert Gibb. Both specimens eventually came into the possession of Mr Dunlop, who generously handed them over to the authors for investigation, with full permission to have them cut for microscopical examination, and to whom we take this opportunity of expressing our indebtedness.

Osmundites Dunlopi, n.sp.

(Plates I., II., and III., figs. 1–16.)

The specimen is preserved in silica, and the plant appears to have suffered a certain amount of decay and attrition before it finally became embedded in the rock. The fossil was collected *in situ*, and impressions of the leaves of *Cladophebis denticulata*, Brongt. sp., were also found in the same bed. The specimen measured 9 cm. across its widest, and 6 cm. across its narrowest part, and contained a portion of the stem about 3 cm. long. The stem itself was to be seen in transverse section on both surfaces of the block; but the greater part of the fossil consisted of a very large number of overlapping leaf-bases packed closely round the axis (Pl. I., fig. 1). The stem itself is about 17 mm. in diameter, and its external limit is indicated by the letter *a* in the figure. The outer region of the cortex is sclerotic, and stands out clearly even in surface view.

Fig. 2, Pl. I., is a photograph of a transverse section, and it shows that, while the sclerotic tissues are fairly well preserved, the thin-walled tissues had decayed before fossilisation, leaving spaces now filled with finely granular matter in which the cellular structure is only rarely indicated. In no case, however, do these spaces represent actual lacunæ, and it may be safely assumed that in life they were occupied by thin-walled tissues analogous to those present in the corresponding regions in the other species of the order.

The wide central pith is represented by a space that is surrounded by an almost continuous ring of xylem about 5 mm. in diameter (fig. 2, *xy.*), which in the fossil has become accidentally fractured at several points. Neither the inner cortex (fig. 2, *i.c.*) nor the peripheral tissues of the stele have been preserved, but they have left a space traversed by several of the departing leaf-traces. The outer region of the cortex (fig. 2, *o.c.*) was sclerotic, and at certain points, which appear as dark patches, it is still in sufficiently good condition to show that it consisted of narrow, thick-walled fibrous elements. The leaf-traces in this sclerotic region were surrounded by a sheath of parenchyma continuous with that of the inner cortex, but it has decayed away, and the leaf-traces appear to lie loosely in so many cavities in the sclerotic outer cortex. Some other smaller light-coloured spaces are also present in the outer cortex (fig. 2, *R.*), which represent roots cut across in various directions as they pass outwards.

The actual limit of the stem itself coincides with the periphery of the cortical sclerenchyma (fig. 2, *a.*), and this is surrounded by a thick coating of closely adpressed leaf-bases which may have been more or less concrescent in close proximity to the axis. In this region of the fossil, however, each leaf-base is distinguished by a special ring of dense sclerenchyma which is continuous below with the outer cortex of the stem. The space between the separate sclerotic rings is occupied by a large number of small sclerotic strands of irregular and varied form, scattered in a matrix of finely granular matter, to which attention will be presently directed.

At first sight the sclerotic rings of the leaf-bases appear to increase in size gradually towards without, at the same time becoming tangentially flattened and variously twisted and contorted. If, however, the coating of leaf-traces be more closely scrutinised as a whole, four more or less distinctly concentric zones (fig. 2, *sc. L.*) can be made out in which the sclerotic rings are especially ill-developed and small in size. These zones successively interrupt the regularity of the increase in size of the leaf-bases towards without, and no doubt they represent zones of scale-leaves with abortive laminæ similar to those occurring in certain of the modern *Osmundaceæ*.

Detailed Description of the Stem.

The most important anatomical character of this species is the almost complete absence of leaf-gaps in the xylem ring of the stem. The fact is that most of the leaf-traces, if not all, depart without in any way interrupting the continuity of the xylem ring, so that the "medullary rays" characteristic of the Osmundaceous stele in general are almost or completely absent. The xylem ring is irregularly and rather deeply indented along both its margins (Pl. I., fig. 3), and before or during fossilisation it became crushed at some points and broken right across at others. Most of these breaks in the xylem ring are clearly due to accident, but it is just possible that some of them may have been occupied by thin-walled cells which decayed before fossilisation. Even if such medullary rays actually were present in the living plant, they must

have been extremely narrow and very rare. Figs. 3, Pl. I., and 4 and 5, Pl. II., illustrate the manner in which most of the leaf-traces, if not all, left the stele; and reference to the longitudinal sections (Pl. II., figs. 6–8) will make it clear that no medullary ray is caused by the departure of the xylem of the leaf-trace, and that the continuity of the deeper portion of the xylem ring is undisturbed. The xylem strand of the leaf-trace, when immediately outside the stele, appears to have a median adaxial group of protoxylem, but it is very indistinct, and once the xylem of the leaf-trace has joined on to that of the stem it can no longer be recognised with certainty. It is not accompanied by parenchyma as in the living *Osmundaceæ*, and must have died out almost at once.

The xylem ring consists of tracheides alone, without any admixture of parenchyma. It is on an average about six or seven elements thick, and the tracheides undergo a marked decrease in size towards without. As seen in transverse section (Pl. II., fig. 9), most of the tracheide walls have a curious speckled appearance, owing to the presence of certain small black masses in their substance: two or even three of these black marks may occur in the same wall. The same fact was noted by PENHALLOW in *Osmundites skidegatensis* (1), and he points out that it is also to be observed in *Osmunda* and *Todea*. The examination of the living genera shows at once that these markings are due to the presence of more than one vertical series of pits on the same wall of the tracheide. The solid unpitted parts of the wall between the several series of pits give rise to the marks seen in transverse section. In *Todea barbara*, *Osmunda cinnamomea*, etc., the small outer tracheides show typical scalariform markings, but in most of the larger ones the single series of pits on the vertical walls is replaced here and there by two or even three series (Pl. II., figs. 10–11). In *Osmundites Dunlopi* the pits seem to have been more or less oval, and in one of the leaf-traces which was cut obliquely the general suggestion is of porose pitting (Pl. II., fig. 12), but in the stem the tracheides are not sufficiently well preserved to make sure of the real nature of their marking. Unfortunately, the small fragment which was available for longitudinal sections was the worst preserved portion of the specimen, and the tracheides showed no markings whatever.

There is no trace of cell-structure left in the pith or in the region of the stele just outside the xylem. In one of the sections, however, the stele is surrounded at a short distance from the xylem ring by a circle of small black marks and dots which undoubtedly represents the endodermis, and consists of the remains of the more persistent parts of its walls. A similar endodermis also clearly outlines the leaf-traces as they pass through the destroyed inner cortex (Pl. II., fig. 13). In this region the leaf-trace is elliptic or at most slightly reniform in section, and its xylem strand has the same form with somewhat enlarged ends. The outline of the leaf-trace remains the same even in the sclerotic outer cortex, but its xylem strand becomes rather more curved, and a median adaxial group of protoxylem now becomes quite distinct.

The Base of the Petiole.

Once the leaf-trace has passed into the petiole it increases rapidly in size and becomes much more curved, taking successively the form of a crescent, a semicircle (Pl. III., fig. 14), an arch, and finally of a horse-shoe with deeply incurved ends. The median protoxylem group becomes broader and more prominent as it passes out. Finally it divides into two, and then into several separate groups (Pl. III., fig. 15), twenty or more being present in the outermost leaf-bases. The phloem is nowhere preserved, and only in a few of the outer leaf-bases are any indications to be found of the thin-walled cells that occupied the space between the leaf-trace and the sclerotic ring of the petiole (Pl. III., fig. 14). A number of isolated strands of sclerenchyma occur in this tissue, scattered on all sides of the leaf-trace and also in its concavity (Pl. VI., fig. 3). They are very irregular in size and form, but two of them are very much larger than the rest and are constant in position. They lie in the two bays formed by the incurved ends of the leaf-trace, and in immediate contact with it. These strands are increasingly conspicuous in the outer leaf-bases (Pl. I., fig. 2, *scl.*).

In the actual living plant the sclerotic ring of each leaf-base was surrounded by thin-walled tissue, which was prolonged on either side of the petiole so as to form two stout and wide stipular wings. This tissue does not exist as such in the fossil, but is represented by the matrix that fills up the spaces between the sclerotic rings of the petioles. The stipules also contained a very large number of thick-walled fibrous elements, which were embedded in this parenchyma, and these still remain *in situ*. They occur for the most part as isolated fibres, but they are also grouped together to form so many strands of various shapes and sizes, which are scattered irregularly throughout the substance of the stipule (Pl. III., fig. 16). A general idea of the distribution of all this sclerenchyma may be obtained from Pl. VI., fig. 3, which is a diagrammatic reconstruction of a section of a leaf-base situated at some distance from the stem. Towards below the leaf-bases all appear to become concrescent by their parenchymatous stipules. The sclerotic strands of the stipules are already present even in this region, but those lying within the sclerotic ring of the petiole do not appear until further out.

The smaller leaf-bases that are supposed to represent scale-leaves do not differ from the rest in structure, except that the xylem of the leaf-trace is very poorly developed. It would seem, indeed, that only a very few tracheides in immediate contact with the protoxylem elements ever become fully differentiated, the rest of the metaxylem remaining permanently thin-walled. This actually proved to be the case in the scale-leaves of *Osmunda Claytoniana* and *O. cinnamomea*. A full-sized leaf-trace is laid down by the meristem of the leaf-rudiment, but their protoxylem elements alone appear to be sufficient to meet the diminished water-supply needed by the abortive leaf throughout its life, and except at the very base of the scale the metaxylem elements remain permanently unthickened and unlignified. This metaxylem, therefore, provides an unusual and instructive example of an undoubted vestigial tissue. Further, it suggests

that the production of scale-leaves was initially due to certain adverse external conditions which so reduced the vegetative energy of the plant that certain of the leaf-rudiments were unable to attain their full development as foliage-leaves. That these abortive leaves have acquired protective and storage functions is a secondary and an incidental phenomenon.

The Root.

Numerous roots run in all directions through the cortex of the stem and through the coating of leaf-bases (*r.* in Pl. I., fig. 2, and Pl. III., figs. 15–16). They bore their way through the stipular wings of the leaf-bases, but are unable to perforate the sclerotic rings. They arise upon the leaf-traces after the latter have become free from the stele of the stem—one from each margin of the leaf-trace (Pl. II., fig. 13, *r.*). No case was found in which the xylem of the root was directly inserted upon that of the stem. Their xylem strand was diarch in every case observed. The roots obtain a cortex of their own while passing through the outer cortex of the stem (*r.* in fig. 2, Pl. I.). At first it consists of a thin-walled inner and a sclerotic outer zone, but in the peripheral region of the fossil it appears to be all thin-walled.

Osmundites Gibbiana, n.sp.

Plate III., figs. 17–19, and Plate IV., fig. 20.

The single specimen of *Osmundites Gibbiana* that was found had the form of a small oval disc measuring 4·5 by 5 cm. in diameter and slightly under 2 cm. in thickness (Pl. III., fig. 17). It consisted of a portion of the stem of the plant surrounded by a thick coat of compacted leaf-bases. Before mineralisation took place, the softer tissues of the leaf-bases in the immediate neighbourhood of the stem had somewhat decayed, causing this part of the fossil to sink inwards and produce a shallow circular trough surrounding the stem, which projected from the centre of the fossil as shown in the figure. The specimen was found loose, but Mr Dunlop, who was present when it was discovered, assures us that there can be no doubt that it came from the same bed as *Osmundites Dunlopi*. The stem itself is about 1·5–1·7 cm. in diameter, and its external limit lies about the point marked *a* in fig. 18, Pl. III. In close proximity to the stem the ensheathing leaf-bases are very tightly packed, but further out they become gradually larger and more distinct, the outermost of all being more or less triangular in section. The state of preservation is much the same as in *Osmundites Dunlopi*.

As seen in section, the axis of the stem is occupied by a fairly wide space representing the pith, which is surrounded by a ring of xylem still well preserved. The inner cortex and the peripheral tissues of the stele were greatly decayed before fossilisation, but the fibrous sclerotic elements of the broad outer cortex (*o.c.*, fig. 18, Pl. III.) were

still in good condition. Numerous leaf-traces are seen traversing the cortex, and in the outer sclerotic region they are surrounded by rhomboidal areas formerly occupied by thin-walled tissue. Beyond the limit of the stem itself, each leaf-base is represented by its own sclerotic ring, and, as already described in *Osmundites Dunlopi*, the space between the rings was occupied in the living plant by the tissues of the more or less concrescent stipular wings of the leaf-bases. As represented by their sclerotic rings, the leaf-bases gradually increase in size towards without, with the exception of two more or less distinct concentric zones of especially small and ill-developed rings apparently belonging to scale-leaves (*sc. L.* in fig. 18, Pl. III.).

Detailed Description of the Stem.

The xylem ring is irregularly oval in outline, possibly owing to compression. It is 2·5 by 4·5 mm. in diameter, and consists of about twenty distinctly separate strands. The strands vary much in form and size (Pl. III., fig. 19), and were separated from each other by tracts of thin-walled tissue corresponding to the "medullary rays" of the modern *Osmundaceæ*. In the fossil, however, this tissue has entirely disappeared. The different forms assumed by the xylem strands are dependent upon their relation to the departing leaf-traces and upon their proximity to the points at which they fuse with each other. The effect of these relations upon the form of the strands will be easiest understood by reference to Pl. VI., fig. 1, which is a diagrammatic plan of the xylem system of *Osmunda regalis*.

It is perfectly clear that the xylem system of the fossil constitutes a precisely similar network, the gaps in which are caused by the departure of xylem to the leaf-traces and give rise to the so-called medullary rays. Referring to the diagram, it is seen that when the leaf-trace xylem enters the stele of the stem its ends join on to the backs of two adjacent strands of the xylem ring. A single strand is thus produced, which, seen in section, is shaped like an arch. The concavity of the arch is at first continuous with the pith, and the protoxylem strand of the leaf-trace is continued downwards in the median region of its inner surface (Pl. III., fig. 19, *xy.*[1]). If this strand is followed down the stem, the two sides of the arch gradually approach each other until they meet and fuse by their inner ends. A small island of parenchyma is thus enclosed within the concavity of the arch surrounding the protoxylem, which may now be regarded as mesarch. As it passes downward, the island of parenchyma gradually becomes smaller until it disappears altogether. The xylem strand is now solid, with a mesarch protoxylem (Pl. III., fig. 19, *xy.*[2]), which, however, below this point rapidly becomes unrecognisable. Concurrently with these changes an indentation appears on the outside of the xylem strand, which progresses inwards until the strand is divided into two. Subsequently the entrance of other leaf-traces joins up these strands with those lying next to them in the xylem ring (Pl. III., fig. 19, *l.t.*[1]), and the same series of changes are again repeated.

The xylem itself is not so well preserved as in *Osmundites Dunlopi*, but on the broader walls of the tracheides dark marks are to be seen which indicate the presence of more than one vertical series of pits. In this species the tracheides are about the same size on the outside of the xylem ring as they are on the inside. There is no parenchyma among the tracheides of the xylem, apart from that surrounding the protoxylem elements.

Although the peripheral tissues of the stele are very much disorganised, distinct indications of the larger sieve-tubes are still to be made out on the outside of the xylem ring (Pl. III., fig. 19, *S.T.*). They occur as wedge-like groups projecting shortly into the medullary rays, and they also form a row on the outside of most of the xylem strands. The outer limit of the stele is clearly defined by the remains of an indubitable endodermis (Pl. III., fig. 19, *en.*), but the structure of the medullary tissue on the inside of the xylem ring is no longer recognisable.

In the inner cortex, just outside the stele, the leaf-traces are elliptic or slightly reniform in section, and their xylem strands are of the same form, with a single median adaxial protoxylem (Pl. III., fig. 11, *l.t.*^{2}) The leaf-trace as a whole is clearly delimited by the remains of an endodermis, and there are indications of a row of sieve-tubes on the abaxial side of the xylem. The leaf-trace itself retains the same form until it has passed through the sclerotic outer cortex of the stem, but its xylem strand becomes more distinctly curved.

Structure of the Leaf-base.

Passing out towards the periphery of the fossil, the leaf-trace undergoes the same series of changes as in *Osmundites Dunlopi*, until in the outermost leaf-bases it has the form of a horse-shoe with deeply inrolled ends. The xylem strand is thin, and so badly preserved that the protoxylem groups are not to be distinguished (Pl. IV., fig. 20, *lt. xy.*). It is usually surrounded by a sheath of crushed elements in which no distinct tissues can be recognised. The thin-walled elements lying between the leaf-trace and the sclerotic ring of the petiole have left no remains ; but several small strands of sclerenchyma are present which are still preserved. They occur on all sides of the leaf-trace and also in its concavity, but the two especially conspicuous strands lying in the bays formed by the incurved ends of the leaf-trace in *Osmundites Dunlopi* are wanting in this species. The leaf-base possessed the same stipular wings as in *O. Dunlopi*, but they are not so thick, and the sclerotic strands they contain are not irregularly scattered, but are arranged in a single series in each wing of the stipule (Pl. IV., fig. 20, *sc. st.*). This is best seen in Pl. VI., fig. 4, which is a diagrammatic restoration of one of the outer leaf-bases. The largest of these strands is nearest the sclerotic ring of the petiole, to which it is often more or less attached, and they gradually decrease in size towards the thin edge of the stipule. The larger strands are distinctly oblong in form, with the long axis at right angles to the surface. The stipular wings were probably more or less

concrescent in close proximity to the stem, as in the modern *Osmundaceæ*. As in *Osmundites Dunlopi*, the xylem strands of the small leaf-bases supposed to belong to scale-leaves were very badly preserved, and it seems probable that those elements only of the metaxylem which were in immediate contact with the protoxylem groups were ever fully differentiated (Pl. IV., fig. 20, *Sc.L.*).

The Roots.

The root steles in this species are very small and delicate, with a diarch xylem strand of very few elements. They arise from the margins of the leaf-traces as they pass through the inner cortex of the stem; apparently not in pairs, but one from each leaf-trace. The root does not obtain a cortex of its own in its passage through the stem, and those that occur in the coating of leaf-bases are so badly preserved that nothing can be made out in them except that they seem to have had no cortical sclerenchyma at all.

Affinities.

The two fossil stems just described agree so exactly in all essential characters with the stems of the modern *Osmundaceæ* that we have no hesitation in including them in this order. Again, they differ from each other so much in detail, they undoubtedly represent two distinct species. On the other hand, it is a very difficult matter to decide whether they belong to the same genus or not, and, in any case, whether they may be identified either with the modern genus *Osmunda* or with *Todea*. In the first place, a careful examination of the stocks of the living representatives of the order only provided a single morphological criterion whereby any given Osmundaceous stock may be definitely assigned to one or the other of the two genera. This distinction is the presence of a transverse commissure formed by the fusion of the upper part of the stipular wings across the adaxial side of the petiole in the Todeas (*T. barbara*, *T. superba*, *T. hymenophylloides*, and *T. Frazeri*), which appears to be entirely absent in the Osmundas (*O. regalis*, *O. Javanica*, *O. cinnamomea*, *O. Claytoniana*). Unfortunately, this does not help us at all with the fossils, because the preservation is not good enough to determine whether a transverse commissure was present or not in either of them.

The only thing to be done, therefore, is to obtain some convenient and reliable anatomical characters which will serve to distinguish between the several living species of the whole order, considered separately and without respect to the genera to which they belong, and then to apply these to the fossils. Such distinctive characters proved, however, to be very difficult to discover; in fact, we have been reduced to the selection of the sclerenchyma in the base of the petiole. The arrangement of the sclerotic tissues in most Ferns is admittedly a variable and insecure feature for such a purpose, but it was found that in the *Osmundaceæ* the various sclerotic strands that occur in the base

of the fully developed petiole are distributed in a manner characteristic of, and practically constant in, each species examined. At the same time, it varies sufficiently from one species to another to render it suitable for the purpose of comparison. The diagrams given in the figs. 6–12, Pl. VI., indicate the arrangement of the sclerenchyma as seen in a section taken about half-way up the stipular region of the petiole in the various living species examined. On comparing them with the fossils, it is seen at once that the leaf-base of *Osmundites Dunlopi* (fig. 3, Pl. VI.) comes very near that of *Todea barbara* (fig. 7, Pl. VI.); while *Osmundites Gibbiana* (fig. 4, Pl. VI.) (although in some respects unique) approaches nearest to *Osmunda regalis* and *O. Javanica* (Pl. VI., figs. 6 and 8.).

While referring to these diagrams, it should also be mentioned that the two American species, *Osmunda cinnamomea* (Pl. VI., fig. 11) and *O. Claytoniana* (Pl. VII., fig. 12) distinguish themselves from all the rest by the fact that their sclerotic ring is not homogeneous, but masses of specially dense and thick-walled elements occur at certain well-defined points in it.

In the stem itself the most important anatomical character that shows any considerable variation in the living species (apart from *Osmunda cinnamomea*) is the extent of the interruption in the continuity of the xylem ring caused by the departure of the leaf-traces. *Osmunda regalis* may be taken to represent one extreme of this variation, in which the xylem ring is broken up into so many distinctly separate strands which are quite free from one another, at any rate over part of their course (Pl. VI., fig. 1). The other extreme is represented by *Todea barbara* and *T. superba*, in which the strands are fused with each other and with the xylem of the leaf-traces, so as to form continuous bands often of considerable extent (Pl. VI., fig. 2). As regards the two fossil species, *Osmundites Dunlopi*, with a practically continuous xylem ring, clearly points in the direction of *Todea barbara*, while *Osmundites Gibbiana* points in the direction of *Osmunda regalis*. So far as our own data permit us to judge, it appears that among the living *Osmundaceæ*, *Todea barbara* shows most resemblance to *Osmundites Dunlopi*, and *Osmunda regalis* to *Osmundites Gibbiana*. Nevertheless, it does not follow that the two fossils actually belong to these two genera, and, until their spore-bearing leaves are also known, it is advisable that both should remain in the comprehensive fossil genus *Osmundites*. The question now to be considered is whether our fossils are identical with any of the three other previously described species of the genus. The first of these was found in the year 1847 by Pettko (2) in Tertiary quartz in Hungary, and was described by him in 1850 under the name of *Tubicaulis*. It was again briefly described by Unger (3) in 1854, who correctly named it *Osmundites schemnicensis*. In 1870, *Osmundites Dowkeri* was obtained by Carruthers (4) from the Lower Eocene of Herne Bay, and in 1902 Penhallow (5) described *Osmundites skidegatensis* from the Lower Cretaceous in Canada. Seward and Ford (6) also refer to a section of an unnamed *Osmundites* preserved in the collection of the botanical department of the British Museum, and labelled "New Zealand." Through

the kindness of Dr Rendle, we have been able to examine this specimen, and we find that it is identical with *Osmundites Dunlopi*. The xylem ring of the stele is poorly preserved, and is much more crushed and broken up than in our specimen, many of the pieces being pushed out of alignment with the rest of the ring; nevertheless, we are satisfied that most, if not all, the gaps that occur in it are really true fractures and not medullary rays. In all other respects it corresponds exactly with our specimen, especially in the distribution of the sclerenchyma in the stipules, which are here clearly delimited from each other by brown lines. Seven zones of scale-leaves are visible in the coating of leaf-bases, and, as in our specimen, their xylem strands are very poorly developed. Another fossil stem with structure preserved has been referred by Solms Laubach to *Osmundites* (*Fossil Botany*, p. 172). It was found loose in the alluvium of the lower course of the Lena, in Siberia, and has not yet been fully described.

So far as our fossils are concerned, *Osmundites skidegatensis* may at once be removed from the comparison, for its structure is so unique and extraordinary that it will have to be dealt with apart and in some detail later on. Both *Osmundites Dowkeri* and *O. schemnicensis* clearly belong to the type of xylem ring represented by *Osmunda regalis* and *Osmundites Gibbiana*, and therefore *Osmundites Dunlopi* stands alone, and is undoubtedly a distinct and a new species.

Through the courtesy of Dr A. Smith Woodward, F.R.S., we have been able to examine a section of Carruthers' specimen of *Osmundites Dowkeri*, and, as will be presently shown, so many points of difference are to be found between it and *O. Gibbiana* that they must clearly be held to represent two separate species. As regards *Osmundites schemnicensis*, the descriptions given by Pettko and Unger are not detailed enough for an accurate comparison; but, so far as may be judged from their figures, it appears to be distinct from *O. Gibbiana*, while it is very near to, possibly even identical with, *O. Dowkeri*.

Osmundites Dowkeri, Carruthers.

(Plate IV., fig. 21.)

1870. *Osmundites Dowkeri*, Carr., *Quart. Jour. Geol. Soc. Lond.*, vol. xxvi. p. 349, pl. xxiv. figs. 1–3, and pl. xxv. figs. 1–4.

A strong dissimilarity in general appearance is at once apparent between *Osmundites Gibbiana* and *O. Dowkeri*, if fig. 18, Pl. IV., be compared with fig. 21, Pl. IV., which is a photograph of a section of the latter. The numerous differences in detail which also exist will now be pointed out. Unfortunately, from our point of view, Carruthers' specimen had been attacked by the mycelium of a fungus which had wrought so great destruction among the tissues, before fossilisation set in, that accurate interpretation of their original structure is rendered somewhat difficult. The delicate septate hyphæ of the fungus are most beautifully preserved, and at certain points they seem to have

formed numbers of small, oval, dark-coloured spores. The stele of *Osmundites Dowkeri* in all essentials closely resembles that of *O. Gibbiana*. There are about thirty separate strands in the xylem ring, and many of the tracheides have more than one vertical series of pits on their broader walls. The phloem is too badly preserved to show whether there was a porose layer or not. The pith is still intact and fairly well preserved (Pl. IV., fig. 21, *P.*). It consisted of rather thick-walled parenchymatous cells with conspicuous coarse, irregular reticulate markings on their walls. The elements at the periphery of the pith are smaller and more sclerotic than the rest, and some of the central cells appear to be thin-walled, but this may be an accident of preservation. A marked feature of *Osmundites Dowkeri* is the strong curve taken up by the xylem of the leaf-trace almost immediately it has left the stele (Pl. IV., fig. 21). In *O. Gibbiana* the curve is only very slight until the leaf-trace has left the cortex of the stem. The coating of leaf-bases is well preserved in *Osmundites Dowkeri*; even the parenchymatous tissues of the stipules are still present. Towards the periphery of the section the limits between the separate stipules are clearly marked out by brown lines, although in close proximity to the axis they are all concrescent. The diagram text fig. 5 represents a restoration of a section of the leaf-base of *Osmundites Dowkeri*, showing the distribution of the sclerenchyma, and it is altogether distinct from that of *O. Gibbiana* (Pl. VI., fig. 4). The stipule as a whole is much thicker in proportion to its length, and, in particular, the single series of oblong sclerotic strands in the wing of *Osmundites Gibbiana* are here replaced by a number of more or less rounded strands scattered irregularly and at different levels in the thickness of the stipule. In both species isolated strands of sclerenchyma occur within the sclerotic ring, but the stout band of sclerenchyma that lies in contact with the concave surface of the leaf-trace in *Osmundites Dowkeri* was not to be found in *O. Gibbiana*.

The Root.

The roots arise one at a time, or possibly sometimes in pairs, at the angles of the leaf-gap, before the leaf-trace is yet free from the stele of the stem. The xylem strand is always diarch, and the root obtains a cortex of its own while passing through the outer cortex of the stem. The outer zone of this cortex is at first heavily sclerotic, but as the root passes outward it becomes all more or less thin-walled. The number of roots that occur among the leaf-bases is very large, and they differ considerably in size and structure. The smallest roots are exceedingly delicate, with a very small stele. The endodermis consists of some six to nine rather flattened cells, and these are surrounded by the same number of especially large cortical cells filled with some finely granular matter. There is no reason, however, to believe that these smaller roots belong to some other plant. They are very probably branches borne by the larger main roots; indeed, one case of branching was actually observed. Moreover, excellent examples of branching roots within the coating of leaf-bases are provided by *Osmunda Claytoniana*

and *O. cinnamomea*. In these plants the young roots that arise near the growing point of the stem are not able to bore their way straight out through the coating of leaf-bases. The older leaf-bases near the outside appear to be too tough for them to penetrate. So they eventually turn upwards and become flattened out between the closely packed leaf-bases. At the same time they branch copiously in a distichous manner. Many of these roots never reach the soil until the old leaf-bases lying outside them rot away. Some of them, however, may do so by growing on upwards until they have over-topped the coating of leaf-bases.

Osmundites skidegatensis, Penhallow.

Plate IV., figs. 22, 23, and Plate V., figs. 24–28.

1902. *Osmundites skidegatensis*, Penhallow, *Trans. Roy. Soc. Canada*, ser. 2, vol. viii. p. 3, pls. i.–iv., figs. 1–8.

1902. *Osmundites skidegatensis*, Penhallow, *ibid.* p. 32, pls. vii.–xi.

Our attention was first drawn to the remarkable structure of this plant by the inspection of the admirable photographs given by Professor PENHALLOW in his original description of the species, and on communicating with him he at once most generously presented us with a transverse section of his fossil. A photograph of this section is shown on Pl. IV, fig. 22. The section includes but little more of the stem than the stele itself, and since this alone measures as much as 2·4 cm. in diameter, it follows that the whole stock, with its coating of leaf-bases, must have been very much larger than that of any known member of the *Osmundaceæ*. The structure of this plant has such an important bearing upon the discussion of the vascular morphology of the order that it is necessary, even at the risk of some repetition, to deal with it here in full detail, in order that a proper appreciation of its relation to the other species may be attained.

STRUCTURE OF THE STEM.

The xylem ring of the stele contains about fifty very distinctly separate strands, and, so far as the relation of these strands to one another and to the entering leaf-traces is concerned, it clearly belongs to the type represented by *Osmunda regalis*. The xylem ring surrounds a very wide pith (Pl. IV., figs. 22 and 23, *P.*), which consists partly of thin-walled and partly of thick-walled sclerotic cells. The latter occur in scattered groups of various forms and sizes. The most startling point in its anatomy, however, is the fact that the departure of each leaf-trace interrupts the continuity of the whole vascular ring. Not only is there a gap left in the xylem ring, but also in the phloem, and through this gap the tissue of the pith becomes perfectly continuous with that of the cortex in the axil of the leaf-trace (Pl. IV., fig. 22, *b.*, fig. 23, *lg.*, and Pl. V., fig. 25). But this is not all, for the inner margin of the xylem is surrounded by a ring of internal phloem (Pl. IV., fig. 23, *int. ph.*, and Pl. V., figs. 24, and 27, *int. ph.*), and at the

departure of each leaf-trace this internal phloem becomes continuous with the external phloem along both sides of the leaf-gap (Pl. V., figs. 24, 25, and 26, *l.g. ph.*). The external phloem presents the same peculiarities as that in the modern *Osmundaceæ*. The sieve-tubes of the metaphloem are plentiful and large, and they are separated from the tracheides of the xylem by a broad stratum of parenchyma four to five cells thick (Pl. V., figs. 25 and 26, *par.*). There is no true protophloem, but the metaphloem is immediately followed towards without by eight to ten layers of cells strongly elongated in a tangential direction (Pl. V., figs. 25 and 26, *p.l.*). Their walls sometimes show clear indications of a pitted or sieve-plate marking, and beyond doubt they correspond to the porose layers first mentioned by ZENETTI (7) in the living *Osmundaceæ*. The more peripheral elements of this porose zone are narrower and less tangentially elongated than the rest, and they may perhaps be counted as a normal pericycle. No layer resembling an endodermis can be distinguished in the fossil, and, as stated by PENHALLOW, it is practically impossible to set a definite limit to the stele.

The internal phloem consists of metaphloem alone (Pl. V., fig. 27, *int. ph.*), and as before the sieve-tubes are separated from the inner margin of the xylem by about five layers of parenchyma (Pl. V., fig. 27, *par.*). The porose cells are entirely absent on the inside of the xylem ring, nor are there any tissues present that can be identified with a pericycle or an endodermis.

The internal and external metaphloems are connected above the point of departure of each leaf-trace by two bands of sieve-tubes extending along the two sides of the leaf-gap (Pl. V., figs. 24, 25, and 26, *l.g. ph.*). These sieve-tubes are, as elsewhere, separated from the xylem by about five layers of parenchyma (Pl. V., figs. 25 and 26, *par.*). The median region of the leaf-gap is occupied by a large mass of starch-bearing sclerenchyma, which extends inwards directly into the pith and outwards into the cortex in the axil of the leaf-trace (Pl. V., figs. 24–26, *l.g. sc.*). Above the leaf-departure the porose layers very soon extend again across the leaf-gap so as to close it up on the outside (Pl. V., fig. 26, *p.l.*). The sclerenchyma in the middle of the leaf-gap is separated from the two bands of sieve-tubes that line the sides by about four layers of thin-walled parenchyma (Pl. V., fig. 25, *par.*^{2}). As the leaf-gap becomes narrower towards above (*cf.* the diagram of *Osmunda regalis*, Plate VI., fig. 1), the sclerenchyma gradually diminishes in quantity until at length the two lateral bands of phloem come into contact in the median region of the gap (Pl. V., fig. 24, *lg.*^{1} and *lg.*^{2}). Still higher up, the two xylem strands themselves fuse together to form a single one. The fusion is at first only partial, beginning in their more central regions, so that the single strand thus formed has a deep groove on its external surface that is still filled by the remains of the median connecting band of phloem (Pl. IV., fig. 23, *xy.*^{1} and *xy.*^{2}).

In order to complete the description of the stele, it is necessary, first of all, to give an account of the structure of the leaf-trace, and then to deal with the disposition of the tissues in the regions lying below the leaf-gap after their entry with the leaf-trace. The leaf-trace itself is very large, and it is already strongly curved, even while still in

the parenchymatous inner cortex of the stem (Pl. IV., fig. 23, *lt.*[1]). The concavity of the curve is entirely occupied by a mass of dark sclerenchyma. The leaf-trace is completely surrounded by phloem, which is separated from the xylem strand by about four or five layers of parenchyma (Pl. V., fig. 28). A true and perfectly distinct protophloem is present on the abaxial side of the trace, lying on the outside of the clearly centripetal metaphloem. The protophloem elements are particularly conspicuous at two points: one on each side of the back of the leaf-trace (Pl. V., fig. 28, *pr.ph.*). This rather curious arrangement is also present in the leaf-traces of the modern *Osmundaceæ*. In the young leaf-rudiment, it is at these points also that the protophloem is first differentiated; and further, when mucilage sacs are present in the pericycle of the leaf-trace, these are the only points on the abaxial side of the leaf-trace where they occur. To return to the fossil, there is no protophloem at all on the abaxial side of the leaf-trace, but the metaphloem is continued round the ends of the xylem by a layer of fairly large sieve-tubes that extends across the whole concave surface (Pl. V., fig. 28, *ad. ph.*). These sieve-tubes are separated from the sclerenchyma in the concavity of the trace by about three layers of thin-walled cells, which may be regarded as pericycle (Pl. V., fig. 28, *par.*[2]), but no endodermal layer can be made out on any side of the trace.

When the leaf-trace enters the stele, the ends of its curved xylem strand fuse with the outer surfaces of two adjacent xylem strands of the stele, so as to form a wide and a very deep arch (Pl. IV., fig. 23, *lt.*[3]). The metaphloem in the concavity of the leaf-trace joins on to that lining the sides of the leaf-gap above, and the median region of the arch is occupied by sclerenchyma continuous with that in the leaf-gap above and with that in the concavity of the leaf-trace (*cf.* text fig. 1). Towards below the inner ends of the xylem arch gradually approach each other (Pl. IV., fig. 23, *lt.*[4]), but before they actually fuse all the phloem lining the concavity of the arch has disappeared. After the fusion, therefore, the xylem strand includes only an island or pocket of sclerenchyma, separated on all sides from the tracheides by several layers of thin-walled parenchyma (Pl. V., fig. 24, *l.g. sc.*). This sclerenchyma is, of course, continuous above with that in the axil of the leaf-trace, but it dies out rapidly towards below, leaving a pocket of parenchyma only (Pl. IV., fig. 23, *xy.*[1] and *xy.*[2]; *cf.* text fig. 1). This in turn eventually disappears, leaving a comparatively narrow strand of solid xylem, with a mesarch group of protoxylem elements near its external periphery (Pl. IV., fig, 23, *xy.*[3]), which may be traced upwards into the endarch protoxylem of the leaf-trace, but when traced downwards finally disappears.

Reference must now be made to a very disconcerting phenomenon that occurs in our section of the fossil—to wit, the presence of a certain amount of internal vascular tissue lying in the pith near to one side of the stele, and just within the normal vascular ring (Pl. IV., figs. 22 and 23, *int. str.*). It consists of about seven radially elongated strands of xylem, lying close together and more or less parallel to one another. The more central ends of these xylem strands are surrounded by phloem similar in structure to that in the corresponding position at the inner margin of the normal xylem ring.

This phloem also projects into the spaces separating the internal xylem strands, and in two cases the adjacent strands were further separated by a broad tract of sclerenchyma (Pl. IV., fig. 23, *scl.*). It was not possible to make out definite protoxylem elements

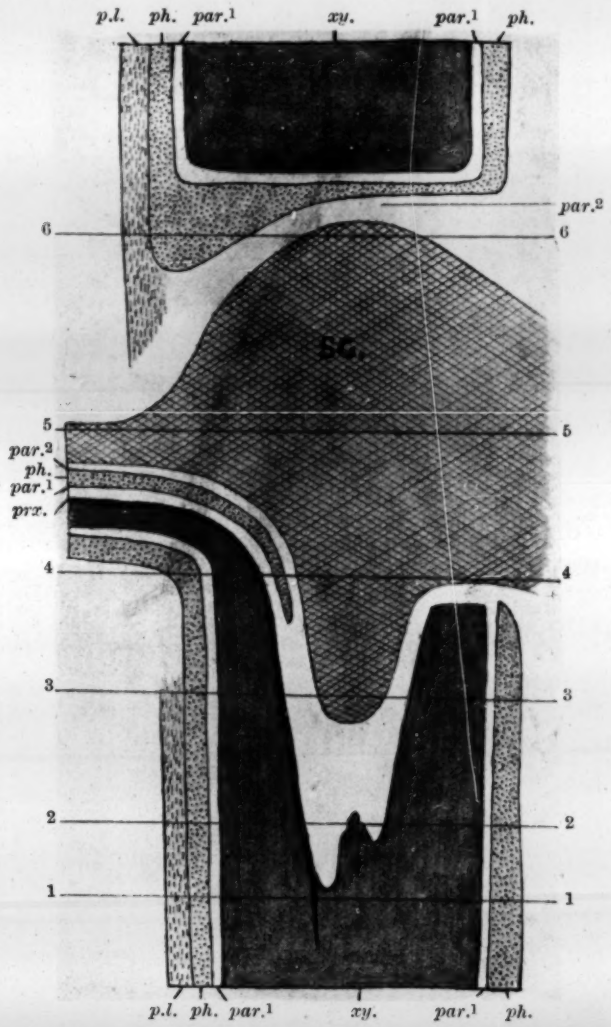


FIG. 1.—Diagrammatic representation of a longitudinal section through the median region of a departing leaf-trace of *Osmundites skidegatensis*. The xylem (*xy.*) is evenly shaded; the protoxylem (*prx.*) is dead black; the metaphloem (*ph.*) is dotted; the porose layers (*p.l.*) are shaded with short lines; the sclerenchyma (*sc.*) is cross-hatched, and the parenchyma (*par.*[1] and *par.*[2]) is left unshaded.

A transverse section taken at the level 1–1 corresponds to the xylem strand *xy.*[4] in fig. 23, Pl. IV.; at the level 2–2 to the strand *xy.*[2] in fig. 23, Pl. IV.; at the level 3–3 to the strand marked *l.g. sc.*[1] in fig. 24, Pl. V.; at the level 4–4 to the departing leaf-trace *lt.*[3] in fig. 23, Pl. IV.; at the level 5–5 to the leaf-gap *lg.* in fig. 23, Pl. IV.; and at the level 6–6 to the leaf-gap marked *l.g. sc.* in fig. 24, Pl. V.

in the strands, but in one of them there was a group of small tracheides near its outer end which possibly represents protoxylem.

These internal vascular strands have to be accepted as actually present in the living plant, for the continuity of their elements with those of the pith is too perfect for their occurrence to be accidental, or for them to be due to the displacement of a broken-off portion of the normal ring which has slipped down from above, as, at first sight, seemed to be the obvious explanation. At the same time, a letter which we have received from Professor PENHALLOW informs us that this internal vascular tissue is not to be found

in a section taken about 5 mm. above the one we possess, nor in another taken about the same distance below. In face of these facts, we are only able to regard it as an unaccountable anomaly.

The thin-walled inner cortex of the stem is beautifully preserved, and is surrounded by a comparatively narrow sclerotic outer cortex (Pl. IV., figs. 22 and 23, *i.c.* and *o.c.*), but the fossil only includes a very small portion of the coating of leaf-bases. Each petiole has a sclerotic ring of its own, and a few isolated strands of sclerenchyma are scattered in the parenchyma lying between it and the leaf-trace. The concave surface of the latter is also bordered by a broad zone of the same sclerotic tissue (Pl. IV., fig. 23, *lt.*[1]). The leaf-bases certainly possessed parenchymatous stipular wings, but even the outermost is cut too near the stem to show the arrangement of the stipular sclerenchyma—if, indeed, they contained any at all.

The Root.

The roots arise directly upon the xylem of the stem, just below the angles of the leaf-gaps. The xylem strand of the root appears to run downwards within the phloem for some distance before it becomes free from the stele of the stem. The xylem of the root is at first rounded in section, and without definite protoxylem elements, but further out it becomes elliptic and diarch. The root obtains a cortex of its own before it has left the tissues of the stem. It consists of two zones, an inner cortex of thin-walled cells and a broad sclerotic outer cortex.

Theoretical Considerations.

According to Jeffrey (8) and Faull (9), the *Osmundaceæ* present a series of reduced structures, so far, at least, as their vascular systems are concerned. This opinion is based upon an attempt to explain the presence of the internal phloem and endodermis discovered by Faull at the inner margin of the xylem ring of *Osmunda cinnamomea*. The vascular system of this plant is supposed by these authors to have degenerated from a dictyostelic cylinder, the leaf-gaps in which have been reduced to the so-called medullary rays. In *Osmunda cinnamomea*, the internal phloem and endodermis of the confluent meristeles is still retained at any rate in the neighbourhood of the branchings. In the other species of the order, the reduction has gone so far that these tissues have entirely disappeared; except, perhaps, in *Todea hymenophylloides*, where, according to Seward and Ford (*l.c.*, p. 249), indications of the internal endodermis are still occasionally to be found. This theory has met with strong opposition from subsequent writers, Boodle (10), Seward and Ford (*l.c.*, p. 255), and Chandler (11), who base their objections chiefly upon the absence of confirmatory evidence in the stem of the young plant. We entirely agree with their criticisms, and prefer to regard the Osmundaceous type of vascular system as directly derived from a primitive

stele possessing a true pith, surrounded by a stout and perfectly continuous ring of xylem. The leaf-traces departed from this stele in a protostelic manner, *i.e.* without leaving any depression or gap into which the external tissues could subside. Further, it is possible to regard this stele as derived in turn from a still more primitive protostele with a solid central mass of xylem.

The evidence provided by the fossil *Osmundaceæ*, so far as it goes, may be taken as distinctly in favour of this point of view. For the requisite perfect continuity of the xylem ring is almost, or, as we believe, actually, realised in *Osmundites Dunlopi*, one of the oldest representatives of the order as yet recognised.* This theory is also in full agreement with the ontogenetic evidence. For in several species it has been shown that a continuous ring of xylem is maintained for some distance upwards in the stem of the young plant (*Todea hymenophylloides*, SEWARD and FORD, *l.c.*, p. 241 ; *T. Frazeri*, CHANDLER, *l.c.*, p. 398 ; *Osmunda Claytoniana* and *O. cinnamomea*, FAULL, *l.c.*, p. 387). Indeed, the leaf-trace occasionally departs in a protostelic manner, even in the mature stem of *Todea barbara* and *T. hymenophylloides*, as we have ourselves observed ; and, judging from the description given by SEWARD and FORD (*cf.* fig. 29, *l.c.*), the same holds good also in *Todea superba*.

It should be noted here that both JEFFREY'S view and our own are opposed to the idea accepted by DE BARY (12), that the vascular system of the *Osmundaceæ* is merely a sympodium formed by the lower ends of the leaf-traces. On the contrary, as already pointed out by LACHMANN (13) and by ZENETTI, the xylem strands undoubtedly constitute a cauline network proper to the stem itself.

Although protesting against the application of a theory of reduction to the order as a whole, we do not, of course, reject, *a priori*, the possibility of its occurrence in any one particular species. In fact, each case must be considered on its own merits, and it is obvious that the structure exhibited by *Osmundites skidegatensis* will have an important bearing upon the discussion. This plant at first sight appears to provide something very like the dictyostelic ancestor postulated by JEFFREY'S theory, and it certainly establishes the fact that the *Osmundaceæ* in the past have reached a far higher degree in complexity than is represented by any of the living species.

In face of this, the possibility that some of the existing species—*Osmunda cinnamomea*, for instance—are reduced can no longer be summarily rejected even by those who are unwilling to apply a theory of reduction to the order as a whole. While admitting this, we venture at the same time to advance an alternative view. In the first place, we would suggest that the type of dictyostely exhibited by *Osmundites skidegatensis* may have been attained by a "cladosiphonic" and not by a "phyllosiphonic" method. That is to say, the internal phloem may have originated by the subsidence of the external phloem into the pith through gaps in the stele produced by the branching of the stem, and not through the gaps due to the departure of the leaf-traces—as

* Since this paragraph was written we have obtained a fossil Osmundaceous stem which indisputably shows a perfectly unbroken ring of xylem.

appears to have been the case in most of the other Pteridophyte dictyosteles and solenosteles.

This idea leads us to regard *Osmunda cinnamomea* as illustrating one of the simpler stages in an ascending series of cladosiphonic structures that have culminated in the complexity of *Osmundites skidegatensis*, and certain points in the anatomy of the former plant seem distinctly in favour of this view. For instance, the internal phloem does not occur in all regions of the stem, but is more or less closely confined to the neighbourhood of the points of branching. Even at these points it is sometimes wanting, as in those cases when the stele branches by a simple median constriction without forming a gap in the xylem ring. Indeed, it seems that it is never present under such conditions; but existing observations on this point are not conclusive. Again, whenever the internal phloem actually is present it is invariably continuous with the external phloem through a gap caused by the branching of the stele; and further, the amount of internal phloem present is closely related to the extent of the opening in the stele. The significance of these facts is accentuated by the phenomena that we observed in a case of branching in *Todea barbara*. Here the xylem ring of the stele opened up in the sinus between the two branches, and the external phloem subsided through the gap for a considerable distance into the medulla of the main axis below the branching. It should be mentioned that in this case neither the porose layer nor the endodermis was decurrent. It is possible, however, that further developments on this line might be met with if other cases of branching could be obtained.

If it were once conceded that the internal phloem obtained admission in this cladosiphonic manner, it is easy to conceive of the subsequent changes that would result in the structure of *Osmundites skidegatensis*. Concurrently with the distension of the stele and the widening of the leaf-gaps incidental to the departure of such large leaf-traces as are possessed by this plant, the phloem would tend to project more and more deeply into the medullary rays both from the inside and from the outside. In fact, according to JEFFREY and FAULL it is already beginning to do so in *Osmunda cinnamomea*. Then the internal and external phloems would meet so as to form a phloem ray, and later the central ground-tissue would project into the median region of this phloem, separating it into two layers lining the sides of the leaf-gap. The two strips of parenchyma lying between these layers of phloem and the xylem now represent all that is left of the original medullary ray tissue. A still further outward extension of the internal ground-tissue would cause the complete disruption of the peripheral tissues of the stele at the level of the departing leaf-trace (*cf.* text fig. 1), and the structure of *Osmundites skidegatensis* would now be attained. Regarded in this light, the continuity of the internal ground-tissue with the external is a secondary and not a primary phenomenon.

The fact that an internal endodermis is always present in *Osmunda cinnamomea*, even in those parts of the stem where no phloem is to be found, may possibly be advanced as an objection to this theory. However, there is, in the first place, no necessity whatever to assume that the internal endodermis actually originated in

continuity with the outer. It is quite probable that the medullary endodermis was already present before ever the stele opened at a branch-gap. In fact, SEWARD and FORD's discovery of an occasional internal endodermis in *Todea hymenophylloides* (*l.c.*, p. 249) that never comes into contact with the external endodermis seems to give support to this view. If, on the other hand, we assume that the two endodermes are really homologous, it is true that initially the phloem must have found its way into the medulla before the endodermis; but it by no means follows that the two tissues should subsequently keep pace with each other in their downward extension. The endodermis may have outstripped the phloem.

However it may eventually be settled, the whole question discussed above provides an instructive example of the importance that should be attached to the proper determination of the morphological status of the various tissues of the stem. The question as to whether the internal ground-tissue of the *Osmundaceæ* is to be held as stelar or not may at first sight appear to be a distinction of merely academic interest; but, nevertheless, the settlement of this point decides whether the order as a whole is to be regarded as an ascending or a descending series.

THE ANCESTRY OF THE OSMUNDACEÆ.

The presence of several vertical series of pits on the broader walls of the tracheides of both modern and fossil *Osmundaceæ* becomes a matter of considerable importance when considering their ancestry, especially since in the primitive fossil species *Osmundites Dunlopi* the tracheides suggest the presence of a reticulate or even porose pitting. It is clear, in fact, that the presence of such markings on the tracheides of any particular fossil can no longer be regarded as an objection to an Osmundaceous affinity. According to the views already expressed above, the stele of such an ancestral type would have a continuous ring of solid xylem, or, in a still more primitive form, even a solid central xylem mass. In both cases the leaf-trace would depart in a protostelic manner, without interrupting the continuity of the xylem, and the protoxylems of the leaf-traces would be more or less decurrent into the xylem of the stem as a mesarch strand. It is further probable, in the more primitive forms, that there would be a peripheral exarch protoxylem of small elements proper to the stem, and apart from the mesarch protoxylem of the leaf-traces. In many of the species already known, the tracheides of the xylem ring diminish markedly in size towards the periphery (*Osmunda regalis*, *Osmundites Dunlopi* and *O. skidegatensis*); although it must be admitted that in the living *Osmundaceæ* the differentiation of the metaxylem elements takes place quite irregularly after the decurrent leaf-trace protoxylems are once fully developed.

If a fossil stem possessing the more primitive of the above-described characters were ever to be found, it would very probably be classed at first sight with the *Botryopterideæ*. This is a conclusion with which we would at once agree, for we regard the

Osmundaceæ as directly descended from an ancestral stock from which at least two other types of structure also arose—that of *Botryopteris* and that of *Zygopteris*.

As far as can be gathered from RENAULT's meagre description of the fossil, it appears to us that *Grammatopteris Rigolotti*, B. Ren. (14), possesses a type of structure that may be regarded as primitively Osmundaceous.

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DESCRIPTION OF FIGURES.

Figs. 1-2, 6-12, 14–18, and 20–24 are untouched photographs. Figs. 3–5, 13, 19, and 24–28 have been made from lightly printed bromide prints, which were used as camera lucida tracings.

The following lettering is used throughout:—*xy.*, xylem strand; *prx.*, protoxylem; *ph.*, phloem; *prph.*, protophloem; *S.T.*, sieve-tubes; *i.c.*, inner cortex; *o.c.*, outer cortex; *p.*, pith; *l.t.*, leaf-trace; *l.g.*, leaf-gap; *r.*, root.

Plate I.

Fig. 1. *Osmundites Dunlopi.* Surface view of the specimen. *a.*, outer limit of stem. (Natural size.)

Fig. 2. *Osmundites Dunlopi.* A transverse section of the specimen. *a.*, outer limit of stem; *xy.*, xylem ring of the stele; *S.L.*, zones of scale-leaves; *scl.*, conspicuous sclerotic strands in the outer leaf-bases. (× about 3.) Slide in the collection of Mr R. Dunlop.

Fig. 3. *Osmundites Dunlopi.* Portion of the xylem ring showing the departure of the leaf-trace xylem. (× 36.) Slide K/1242.*

Plate II.

Figs. 4 and 5. *Osmundites Dunlopi.* Portion of the xylem ring showing the departure of the leaf-trace xylem. (Fig. 4, × 31, slide K/1243; fig. 5, × 36, slide K/1242.)

Figs. 6, 7, 8. *Osmundites Dunlopi.* Longitudinal sections of the xylem ring showing the departure of the leaf-trace xylem. *st. xy.*, stem xylem; *lt. xy.*, leaf-trace xylem. (× 9.) Slides K/1246, K/1244 (figs. 7–8).

Fig. 9. *Osmundites Dunlopi.* Transverse section of small portion of the xylem ring showing the pit-markings on the walls of the tracheides. (× 90.) Slide K/1243.

Figs. 10 and 11. *Osmunda cinnamomea.* Longitudinal sections of the xylem showing the multiseriate pitting of the tracheides. (Fig. 10, × 144; fig. 11, × 155.)

Fig. 12. *Osmundites Dunlopi.* Oblique section of a leaf-trace passing through the inner cortex to show the apparently porose pitting of the tracheides. (× 63.) Slide K/1243.

Fig. 13. *Osmundites Dunlopi.* Transverse section of a leaf-trace passing through the inner cortex to show the origin of the root steles. *en.*, endodermis. (× 20.) Slide in the collection of Mr R. Dunlop.

Plate III.

Fig. 14. *Osmundites Dunlopi.* Transverse section of four leaf-bases in close proximity to the stem. (× 16.) Slide K/1243.

Fig. 15. *Osmundites Dunlopi.* Transverse section of leaf-trace (A) in fig. 14 more highly magnified. *scl.*, sclerotic ring of the petiole. (× 33.) Slide K/1243.

Fig. 16. *Osmundites Dunlopi.* Portion of the coating of leaf-bases to show the sclerotic stands (*sc. st.*) scattered in the spaces once occupied by stipular parenchyma. *scl.*, sclerotic rings of the petioles; *lt. xy.*, xylem of leaf-trace. (× 33.) Slide K/1243.

Fig. 17. *Osmundites Gibbiana.* Surface view of specimen. (Natural size.)

Fig. 18. *Osmundites Gibbiana.* A transverse section of the specimen. *a.*, outer limit of the stem; *xy.*, xylem ring of stem; *S.L.*, zones of scale-leaves. (× 2·5.) Slide K/1249.

Fig. 19. *Osmundites Gibbiana.* Portion of xylem ring of stele. *en.*, endodermis. (× 33.) Slide K/1249.

Plate IV.

Fig. 20. *Osmundites Gibbiana.* Portion of coating of leaf-bases to show the sclerotic strands (*sc. st.*) in the spaces once occupied by stipular parenchyma. *scl.*, sclerotic rings of the petioles; *lt. xy.*, xylem of leaf-trace; *S.L.*, scale-leaf. (× 14.) Slide K/1249.

Fig. 21. *Osmundites Dowkeri.* Transverse section of the stock. *a.*, outer limit of stem; *xy.*, xylem ring of stele. The pith (*p.*) is still preserved. (× about 2.) Slide K/1248.

Fig. 22. *Osmundites skidegatensis.* Transverse section. *xy.*, xylem ring of stele; *p.*, the pith (still intact); *int. str.*, internal vascular strands. (× 2·4.) Slide K/1251.

Fig. 23. *Osmundites skidegatensis.* Portion of the vascular ring of the stem. *ext. ph.*, external phloem; *int. ph.*, internal phloem; *int. str.*, internal vascular strands; *scl.*^{1}, sclerenchyma between xylem strands of normal vascular ring; *scl.*^{2}, sclerenchyma between the internal vascular strands. (× 14.) Slide K/1251.

* Slides indicated by a "K" in the collection of Mr R. Kidston.

Plate V.

Fig. 24. *Osmundites skidegatensis.* Portion of the vascular ring from (A) in fig. 22 more highly magnified. *ext. ph.*, external phloem ; *int. ph.*, internal phloem ; *l.g. ph.*, metaphloem lining the leaf-gap ; *p. l.*, porose layers ; *l.g. sc.*, leaf-gap sclerenchyma. (× 27.) Slide K/1251.

Fig. 25. *Osmundites skidegatensis.* Portion of the vascular ring from (B) in fig. 22 showing the departure of a leaf-trace. *lt.*, the departed leaf-trace ; *lt. ph.*, phloem of the leaf-trace ; *par.*, parenchyma of xylem sheath ; *par.*^{2}, parenchyma separating the phloem from the sclerenchyma of the leaf-gap. Other lettering as in fig. 24. Note the pitmarks on the tracheide wall. (× 110.) Slide K/1251.

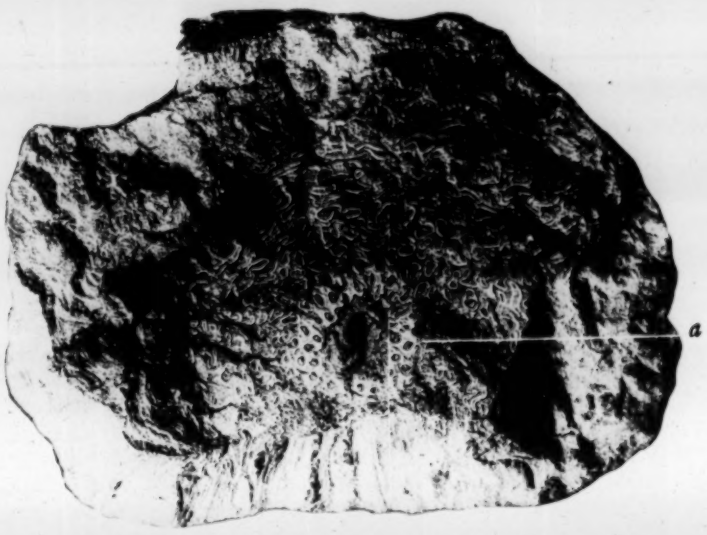
Fig. 26. *Osmundites skidegatensis.* Portion of the vascular ring from (C) in fig. 22 showing a leaf-gap some little distance above the departure of a leaf-trace. Lettering as in fig. 25. (× 105.) Slide K/1251.

Fig. 27. *Osmundites skidegatensis.* The inner margin of a portion of the vascular ring showing the internal phloem (*int. ph.* of fig. 23). Other lettering as in fig. 25. (× 110.) Slide K/1251.

Fig. 28. *Osmundites skidegatensis.* Portion of a transverse section of a leaf-trace passing through the outer cortex of the stem. *ab. ph.*, abaxial metaphloem ; *ad. ph.*, adaxial metaphloem ; *prph.*, protophloem on abaxial side only ; *par.*, parenchyma of xylem sheath ; *par.*^{2}, parenchyma between phloem and sclerenchyma ; *scl.*, sclerenchyma mass in concavity of leaf-trace. (× 84). Slide K/1_51.

Plate VI.

Diagrams ; description on plate.



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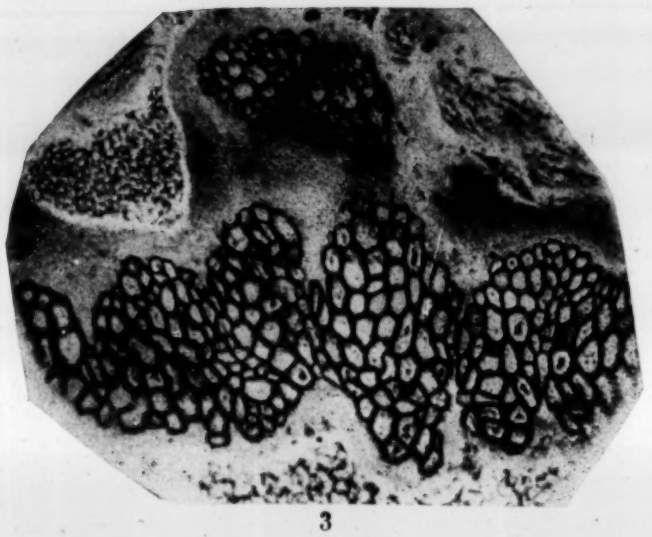

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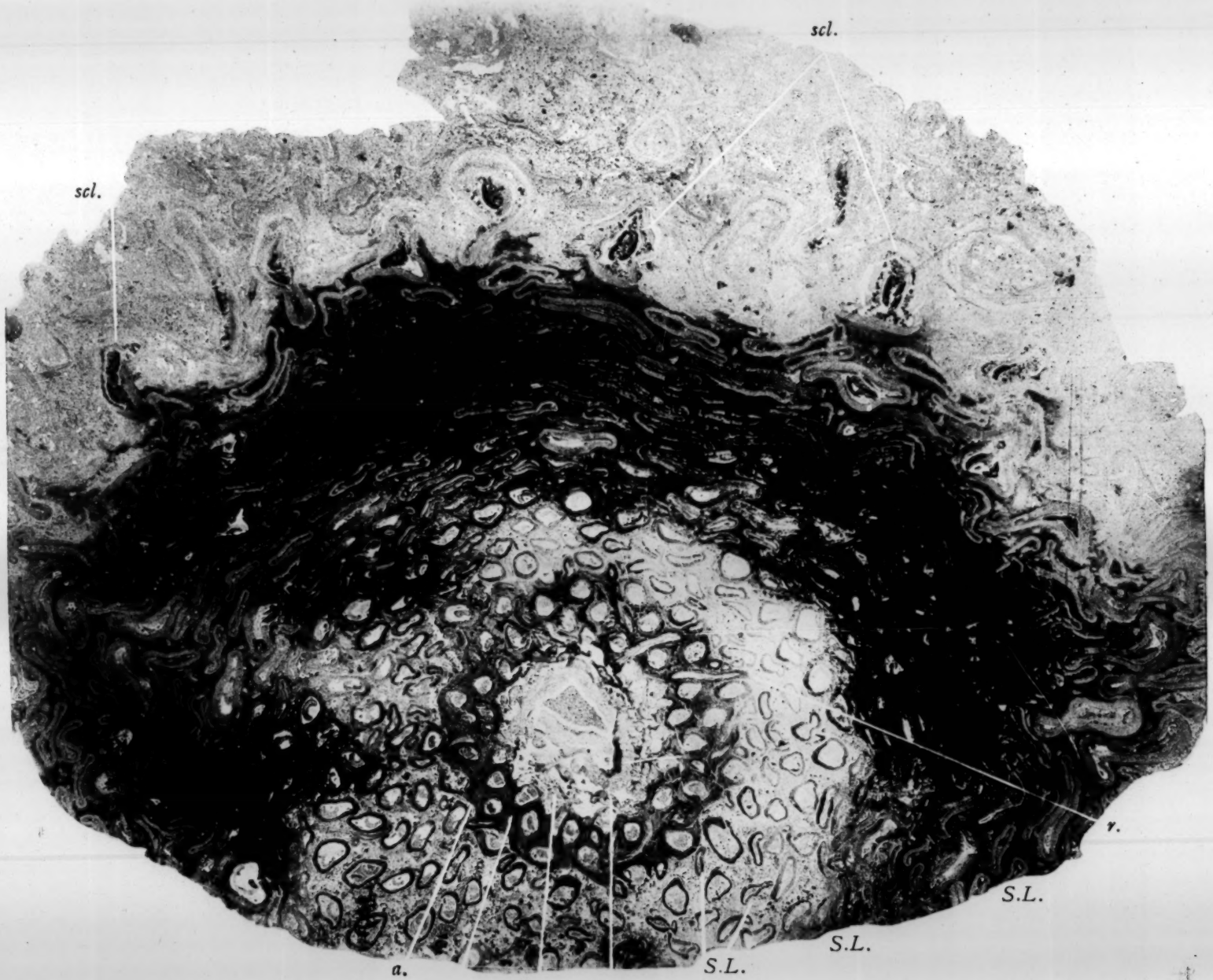

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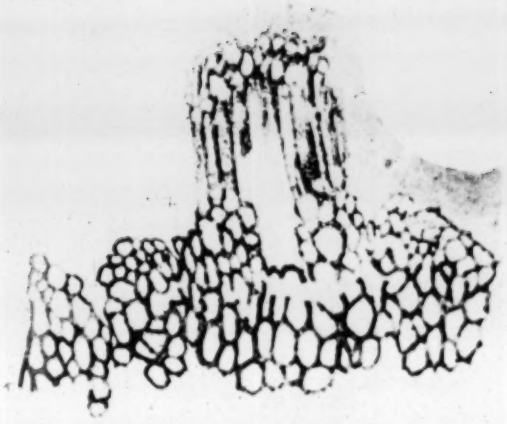
OSMUNDITES DUNLOPI. KIDST. & G.-V. N.SP.



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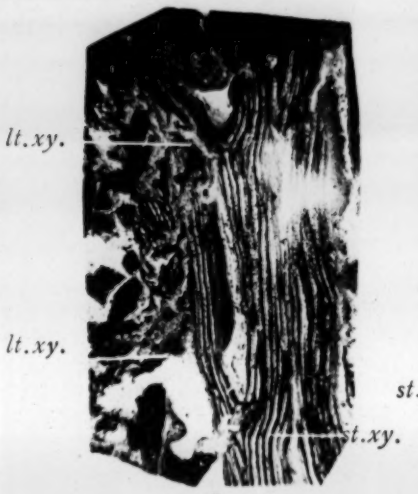

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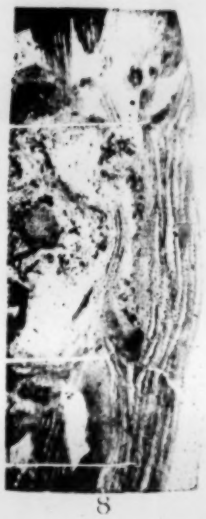

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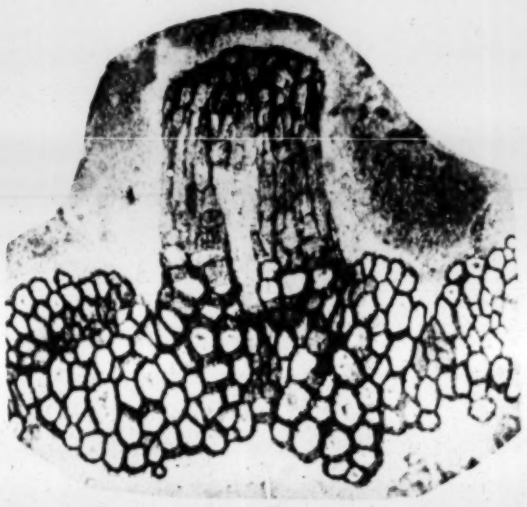

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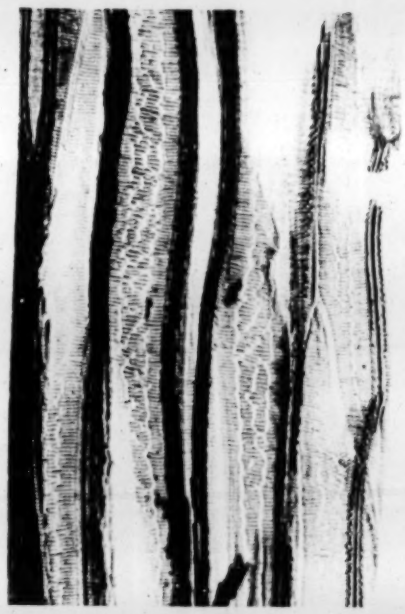

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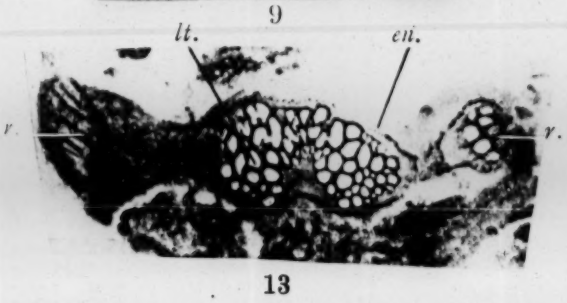

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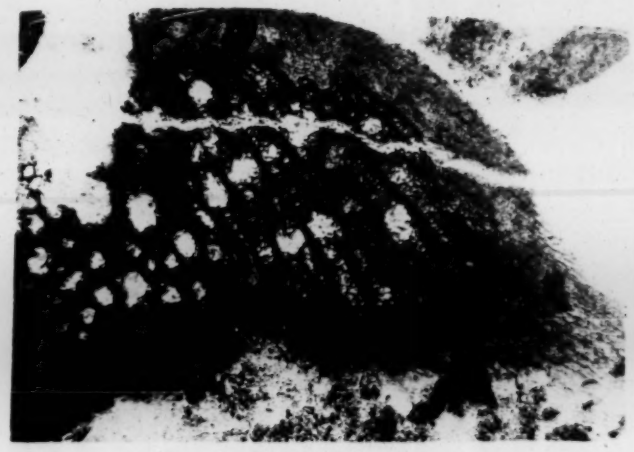

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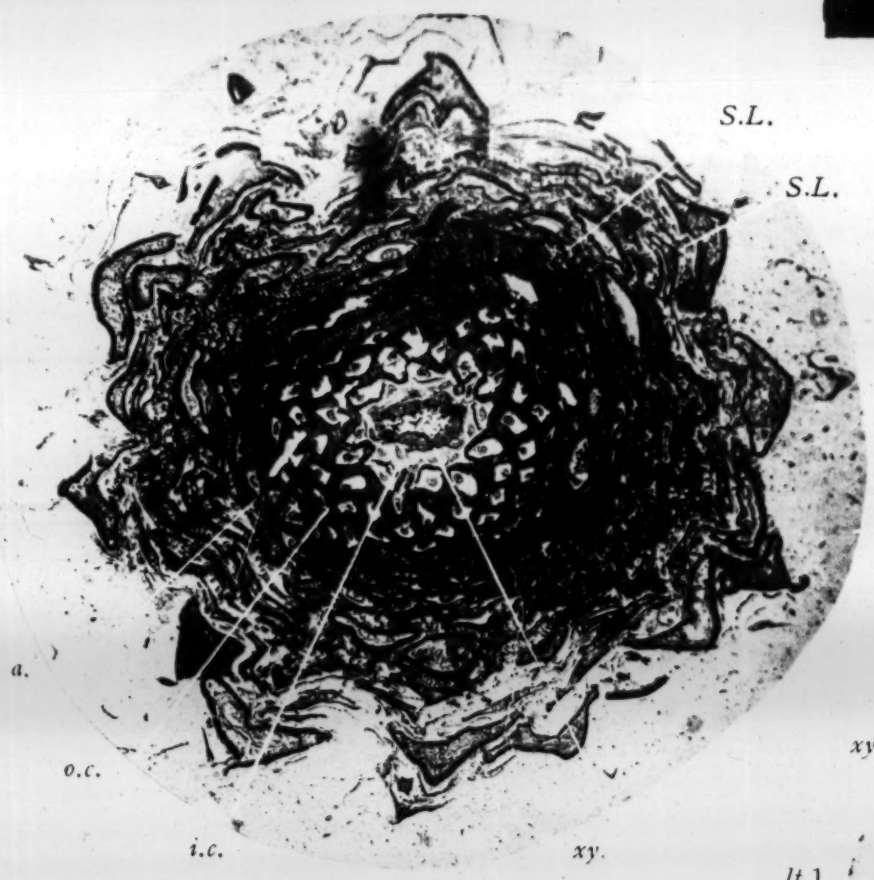
FIGS. 1-9. 12-13. OSMUNDITES DUNLOPI. KIDST. & G.-V. N.SP. FIGS. 10-11. OSMUNDA CINNAMOMEA.

14

16 scl.



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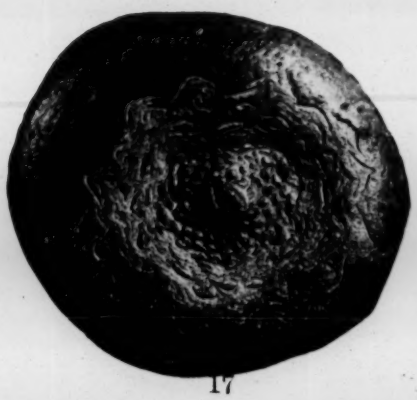

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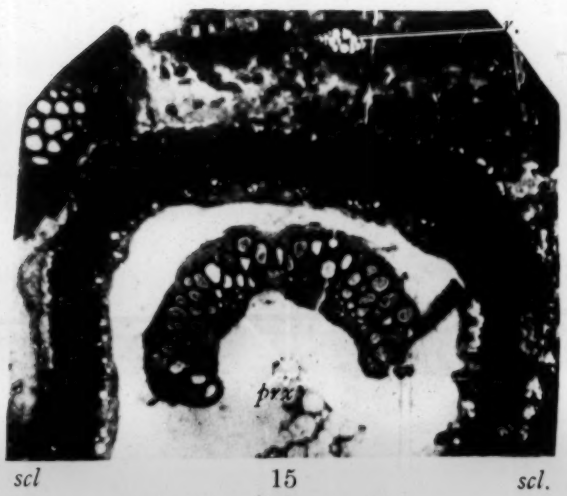

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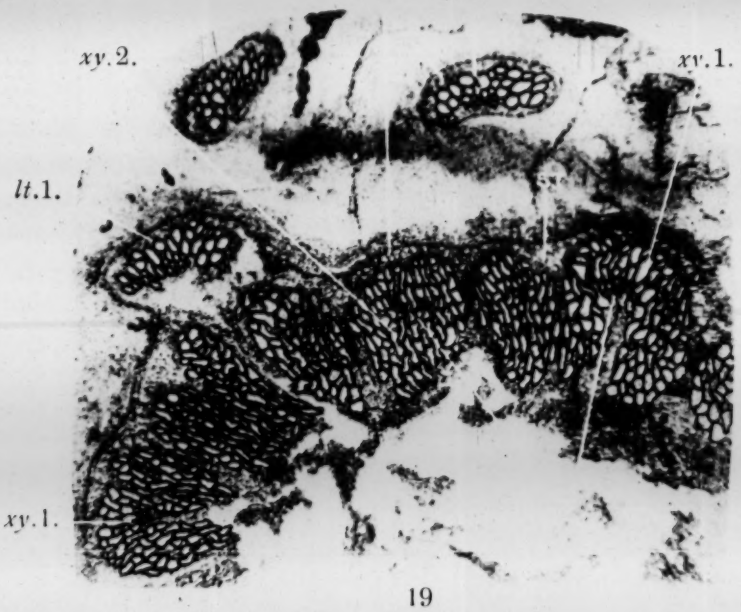
en. lt.2.



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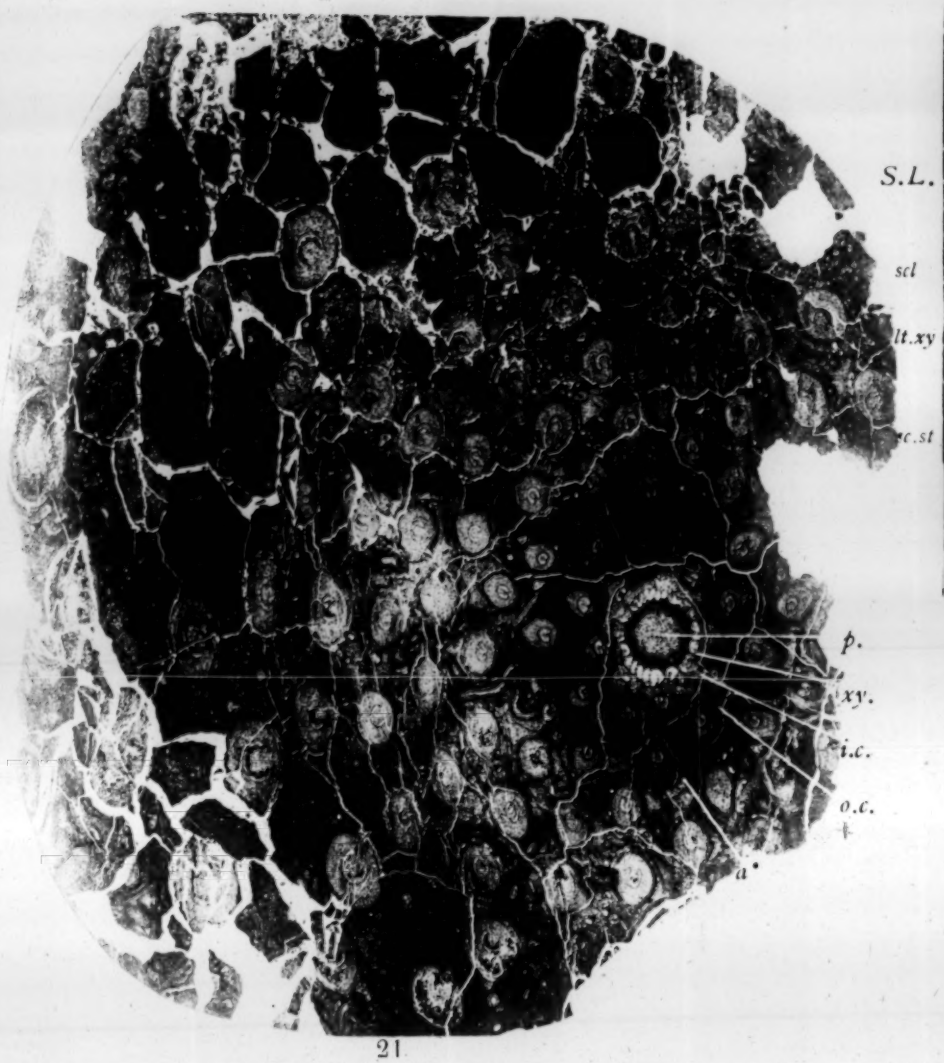
FIGS. 14-16. OSMUNDITES DUNLOPI. KIDST. & G.-V.

FIGS. 17-19. OSMUNDITES GIBBIANA. KIDST. & G.-V. N.SP.



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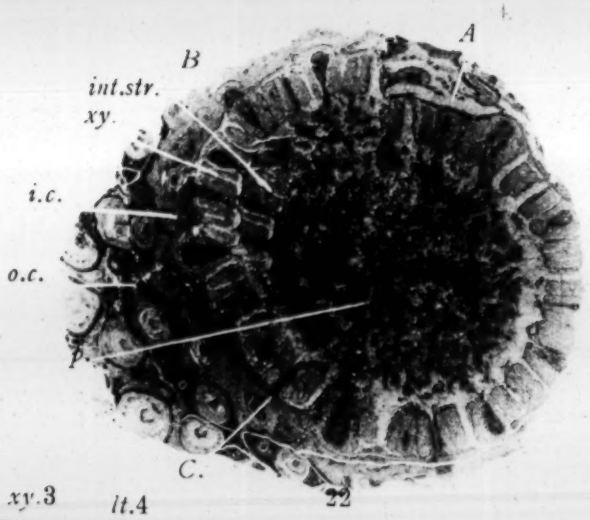

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FIG. 20. OSMUNDITES GIBBIANA. KIDST. & G.-V. FIG. 21. OSMUNDITES DOWKERI. CARR.
FIGS. 22-23. OSMUNDITES SKIDEGATENSIS. PENHALLOW.

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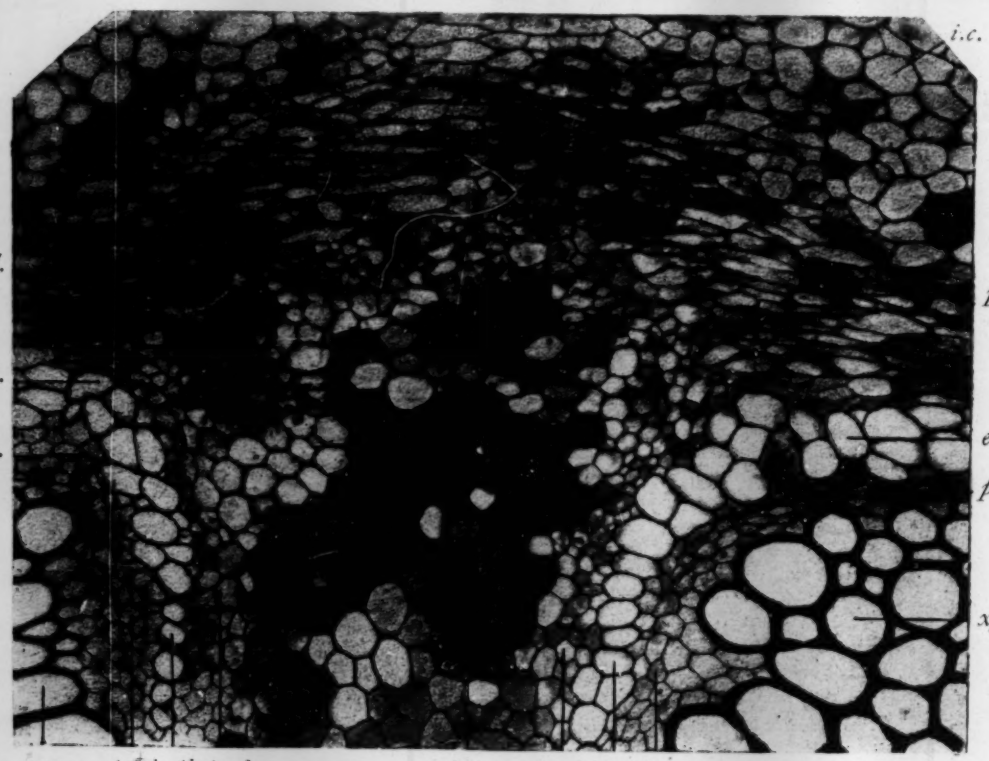

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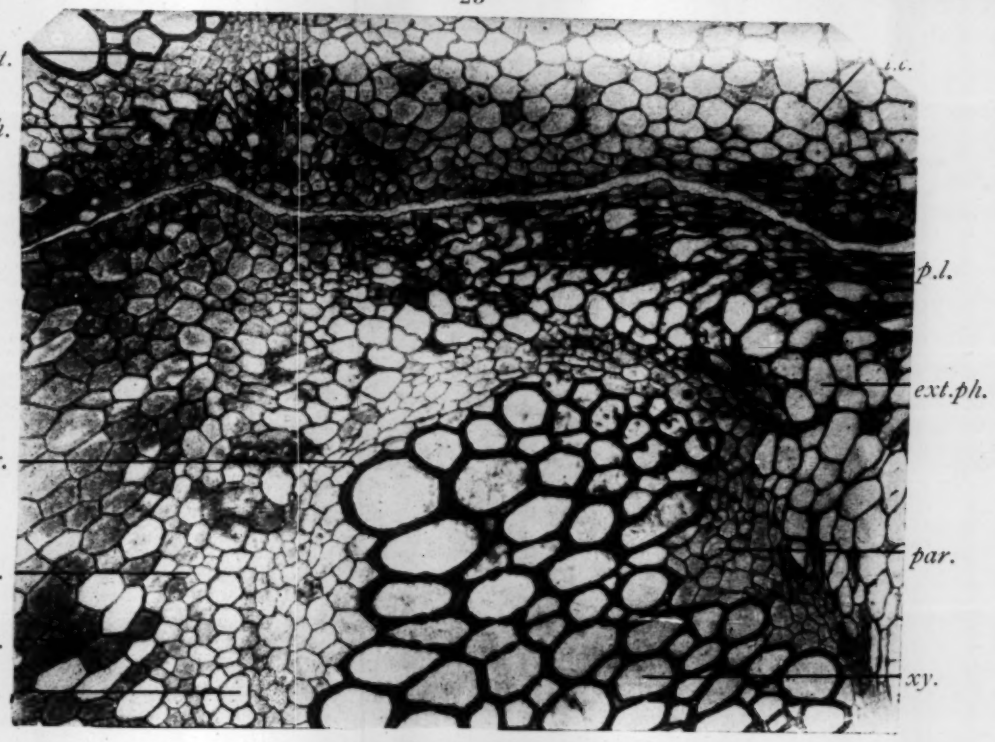
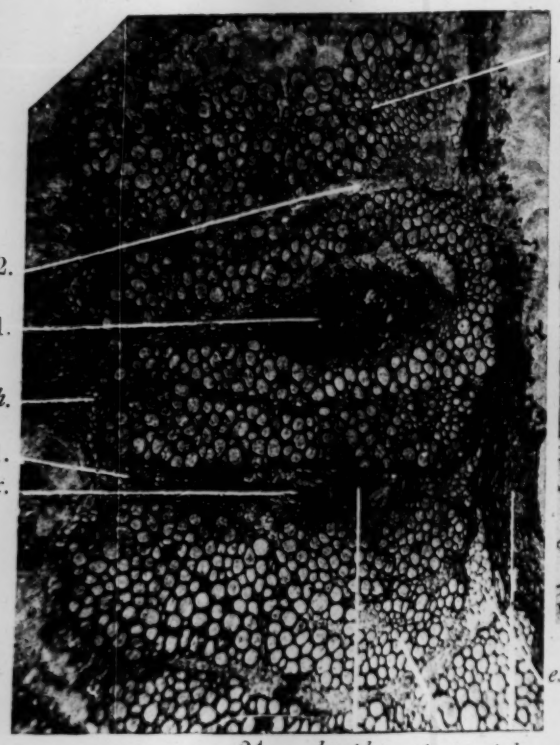
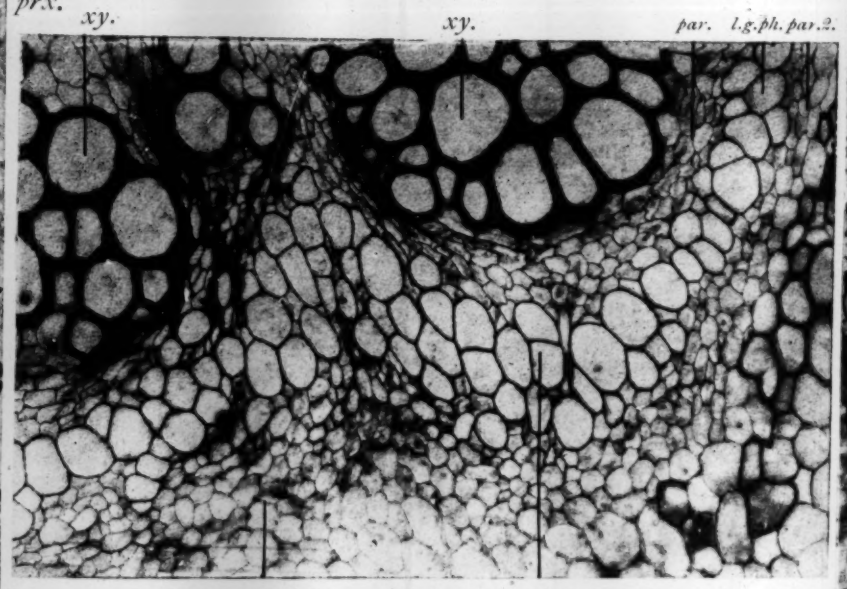
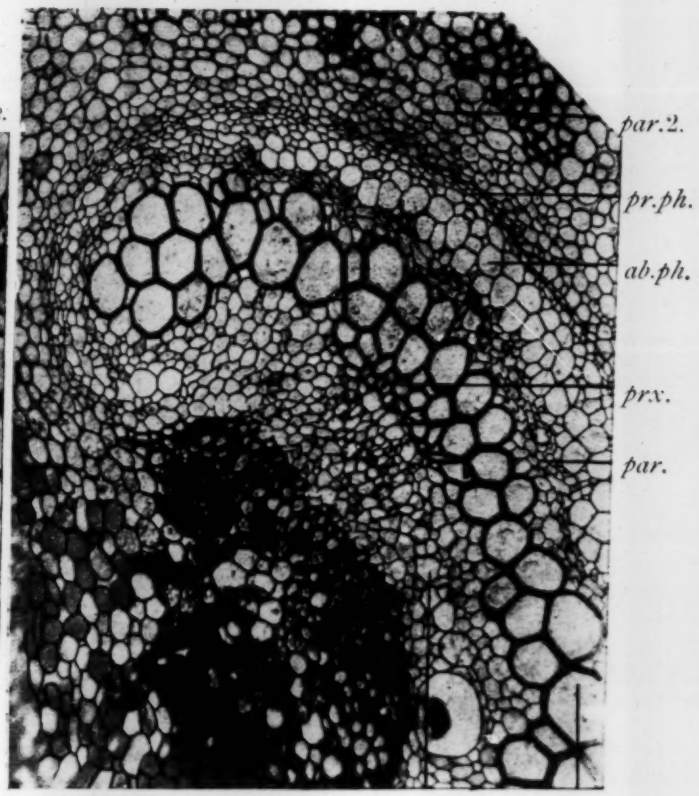




24 *l.g.ph. prx. p.l.*

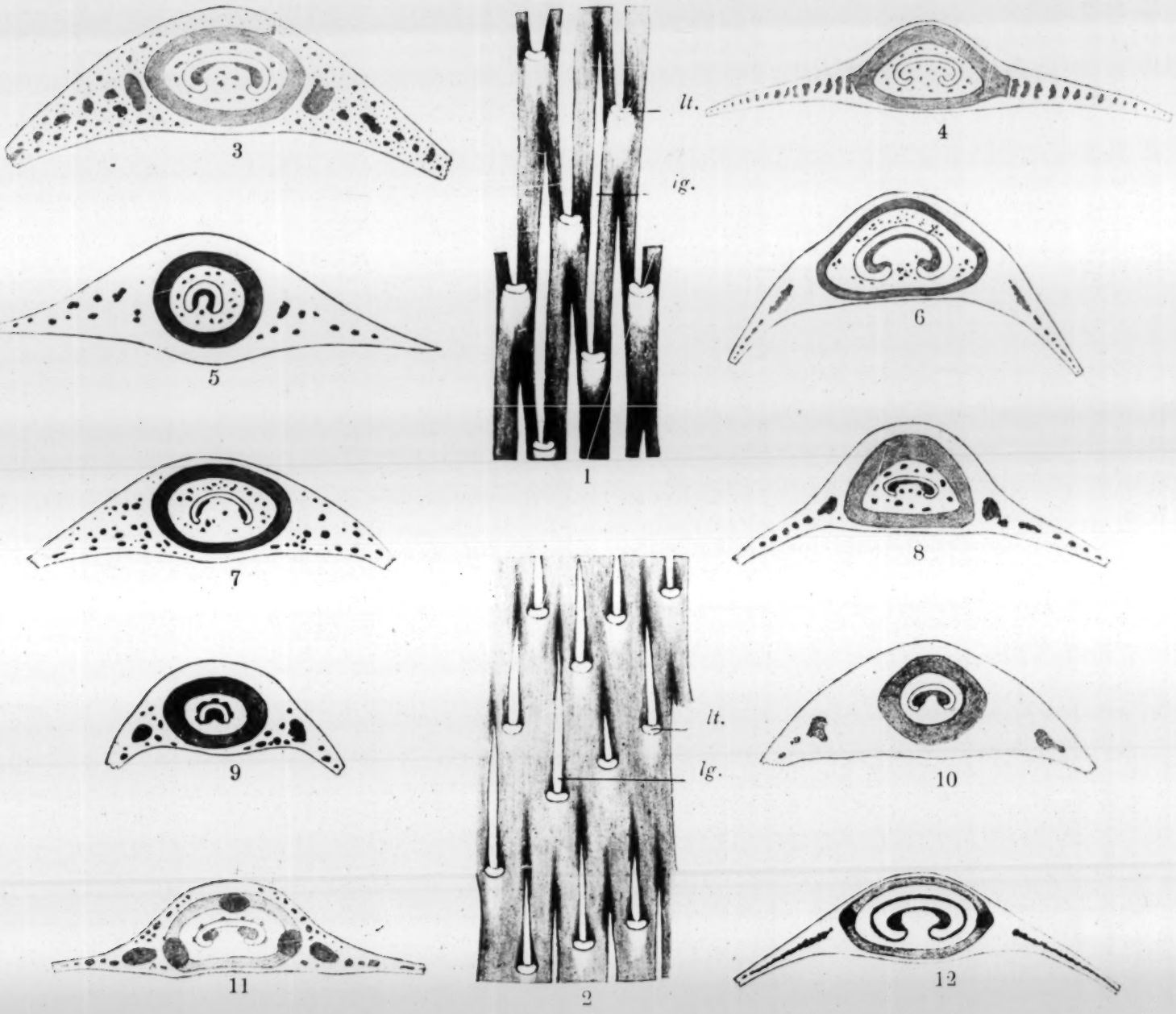


p. 27 *int.S.T.*



sct. 28 *ad.ph.* *xy.*

OSMUNDITES SKIDEGATENSIS. PENHALLOW.



DESCRIPTION OF DIAGRAMS.

1—A representation of a portion of the xylem ring of *Osmunda regalis* seen from without. lt., cut end of a departing leaf trace; lg., leaf gap., (after Lachmann).

2—A representation of a portion of the xylem ring of *Todea barbara* seen from without. Lettering as above. (After Seward & Ford).

3-12—Diagrams of transverse sections taken about the middle of the stipular leaf-bases of various *Osmundaceae* showing the distribution of the sclerenchyma:—The leaf-trace is unshaded.—3, *Osmundites Dunlopi*; 4, *Osmundites Gibbiana*; 5, *Osmundites Dowkeri*; 6, *Osmunda regalis*; 7, *Todea barbara*; 8, *Osmunda Javanica*; 9, *Todea hymenophylloides*; 10, *Todea superba*; 11, *Osmunda cinnamomea*; 12, *Osmunda Claytoniana*.

XXVIII.—A Contribution to the Craniology of the Natives of Borneo, the Malays, the Natives of Formosa, and the Tibetans. By Principal Sir William Turner, K.C.B., D.C.L., F.R.S. (With Five Plates.)

(Read 10th June 1907. Issued separately July 20, 1907.)

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In three memoirs published from time to time in the *Transactions* of this Society * I have described the characters of the crania in several Asiatic races, the bulk of which were natives of India, though a few were from countries adjoining Hindostan. In this memoir I intend to continue my inquiries into the cranial characters of Asiatic people, and to give an account of natives of Borneo, the Malays, the natives of Formosa, and the Tibetans.

BORNEO.

Through the courtesy of a former pupil, Dr Robert E. Adamson, I received between the years 1898 and 1901 fifteen skulls of natives of North Borneo. They were carefully labelled by him with the name of the tribe, and in many specimens also with that of the district from which they had been obtained. Ten skulls were discoloured with smoke, and several retained fragments of dried skin attached to the bones. They had been suspended in the houses of the natives by split cane, which in some specimens had been wound around the skull, so as to enclose it in an open cage with a long loop for suspension; in one skull the loop had been passed through the nose; in two others through a hole artificially made in the sagittal suture. Obviously these skulls had been trophies collected by the head hunters. In several, a part of the occipital bone bounding the foramen magnum had been removed, so as more readily to extract the brain.

In the following description the skulls are arranged in groups in accordance with the tribes to which they belonged.

* Part I., Hill Tribes of the North-East Frontier of India and the People of Burma, *Trans. Roy. Soc. Edin.*, vol. xxxix., 1899; Part II., Aborigines of Chúta Nágpúr, the Central Provinces, Orissa, Veddahs, Negritos, *Transactions*, vol. xl., 1901; Part III., Natives of Madras Presidency, Thugs, Veddahs, Tibetans, Seistanis, *Transactions*, vol. xlv., 1906.

The names of the tribes, their geographical distribution in North Borneo and Sarawak, and the external physical characters of the people have been obtained from the following authorities:—MM. De Quatrefages and Hamy, "Crania Ethnica," 1882; Henry Ling Roth, "The Natives of Sarawak and British North Borneo," 1896, which contains an admirable résumé of the writings of travellers and British residents up to the date of publication, as well as a list of the tribes in Borneo, p. 37, prepared by Mr Charles Hose; Sir Hugh Low, "Sarawak: its Inhabitants and Productions," 1848; Carl Bock, "The Head Hunters of Borneo," 1881, a narrative of travel in the south-east of the island; Alfred C. Haddon, who travelled in the interior of Sarawak, "Head Hunters, Black, White and Brown," 1901; Spencer St John, "Wild Tribes of the North-West Coast of Borneo," in which Land and Sea Dyaks are described (*Trans. Ethnol. Soc. Lond.*, vol. ii. p. 232, 1863); Lieut. C. de Crespigny, R.N., "On Northern Borneo" (*Proc. Roy. Geogr. Soc.*, vol. xvi. p. 171, 1872); F. W. Burbidge, A. Hart Everitt, F. R. O. Maxwell, F. Witti, quoted by Ling Roth. C. Hose, "Natives of Borneo," describes the people of the Baram district, North Sarawak (*Journ. Anth. Inst.*, vol. xxiii. p. 156, 1894); C. Hose and W. M'Dougall, "The Relations between Men and Animals in Sarawak" (*Journ. Anth. Inst.*, vol. xxxi. p. 173, 1901); C. Hose and R. Shelford, "Materials for a Study of Tatu in Borneo" (*Journ. Anth. Inst.*, vol. xxxvi. p. 60, 1906).

Muruts. Table I. Plates I., V.

The Muruts are essentially an inland tribe in Borneo, occupying a district which extends from the Limbang river in Sarawak as far to the north as Mount Kinabalu, 13,700 feet high, in North Borneo. They inhabit the basins of the Padas and the Pagalan rivers, and they constitute an important element in the population of the western part of North Borneo.

The Muruts have a light brown or bronzed skin, which is in part tattooed; the hair is jet black, long, and frequently tied in a knot at the back of the head; the nose is flattened and the stature is said to be low. They pluck out the eyebrows and eyelashes, and during mastication and betel chewing they grind the teeth to the level of the gums. Their clothing is often limited to a loin cloth formed of bark. They live in long houses, are filthy in their habits, indulge freely in intoxicating drinks, and are lethargic in mind and body. They were inveterate head hunters, and the heads suspended in their houses became blackened with smoke. The killing of people for the sake of the heads is being repressed, under the British administration.

Five of the skulls were labelled Murut. In Table I. they are lettered A to E inclusive. A to D were adults. In E the basi-cranial synchondrosis was not ossified, the wisdom teeth were concealed in the bone, but the other permanent teeth were erupted, and the age was probably from 18 to 20. D and E were apparently females, and in each the occipital squama had been in part removed. B, C and E retained the lower jaw.

Norma verticalis.—The cranium in A, B, C and E was elongated, ovoid, and characteristically dolichocephalic in form and proportion; the cephalic index was in each below 75, and in C as low as 69·9. In D, again, the cranial outline was more broadly ovoid, and the cephalic index was 77·7, *i.e.* in the mid-term of the mesaticephalic group. The crania were not ridged in the sagittal line, the parietal eminences were moderate, and the slope of the vault outwards varied in the degree of steepness. Except in D the squamous region was not bulging, and in B and E the greatest breadth was in the

parietal region. The parieto-occipital slope was moderate, the occipital squama projected behind the inion, and there was no artificial flattening. Four were cryptozygous, one phænozygous.

Norma lateralis.—The forehead slightly receded in the male and approached the vertical in the female skulls. The glabella and supraorbital ridges were not prominent and were distinct from the outer upper orbital border, and the frontal bone was flattened in the area between that border and the temporal ridge. The nasion was not depressed except in E, the nasal bridge was not keeled, and tended to be flattened, though with a shallow upward concavity. The occipital arc was the shortest in all the specimens, and, with one exception, the frontal exceeded the parietal arc, though in two only by 1 mm. The crania rested behind on the cerebellar fossæ.

Norma facialis.—In A and C the floor of the nose was separated from the incisive region by a sharp ridge, but in the others the ridge was smoothed down. In all the maxillo-nasal spine was distinct. In B the nares were narrow, the nasal height was more than double the width, and the nasal index was leptorhine; in the others they were wider both absolutely and relatively to the height of the nose, so that the index in A and C was mesorhine and in D and E platyrhine, but the mean index of the series, 50·5, was mesorhine. In B the complete face was long and the index was leptoprosopic, in C it was low and the index was chamæprosopic, but in four skulls the mean maxillo-facial index, 51·2, was leptoprosopic.* In A, B, D the upper jaw was orthognathous, in C feebly mesognathous, and the mean gnathic index computed by FLOWER'S method was 94·2. The relation of the bi-malar to the nasio-malar diameter gave a nasio-malar index † which ranged from 108·4 to 111·4, and the mean, 110, was mesopic and indicated a nose not specially flattened at the root. In A, C, D, E the orbital aperture was rounded, and the mean index, 94·4, was megaseme, in B the breadth was relatively greater, and the index, 87·2, was mesoseme. The hard palate was shallow in A, D, E, and more arched in B and C. In three skulls the palato-maxillary index was hyperbrachyuranic, in one brachyuranic. The teeth, with few exceptions, had been lost; those that remained were betel-stained and worn by use, but not to the level of the gums. The lower jaw had a square projecting chin, the angle was well marked and the muscular ridges were distinct.

The cranial sutures were moderately denticulated. In E the sagittal was closed, but the cranium was not scaphocephalic. A few small Wormian bones were present, though

* In my memoir on the Craniology of the People of Scotland (*Trans. Roy. Soc. Edin.*, 1903), I have explained KOLLMANN'S plan of obtaining facial indices, and have suggested a modification in the grouping as follows:—

	Complete facial index.	Maxillo-facial index.
Leptoprosopic, narrow face, ...	90·1 and upwards	50·1 and upwards
Mesoprosopic, ...	85 to 90	45 to 50
Chamæprosopic, low face, ...	below 85	below 45

† See OLDFIELD THOMAS in *Journ. Anth. Inst.*, vol. xiv. p. 332, 1885. My suggested modification of the divisions of the nasio-malar index is: *platyopic*, low flat-faced profile, index below 106; *pro-opic*, projecting profile, index above 110; profile intermediate in degree, *mesopic*, from 106 to 110 (*Trans. Roy. Soc. Edin.*, vol. xlv. p. 263, 1906).

D had a left epipteric; the alisphenoid articulated freely with the parietal. The mastoids, inion and curved lines were moderate. C had a smooth surface on the left jugal process which had probably articulated with the transverse part of the atlas; there was no 3rd condyl.

The mean cephalic index of the five Murut skulls was 73·9, and if the mesaticephalic D be excluded, only 72·9; in both instances the mean index was dolichocephalic. The mean vertical index in four specimens was 75, metriocephalic. The mean glabello-occipital length was 179·2 mm.; the mean greatest breadth 132·4 mm.; the mean basi-bregmatic height 134·2 mm. As regards the relations of the breadth to the height of the cranium, in only one skull did the breadth exceed the height, and the mean breadth-height index of the four specimens was 100·97; the crania belonged therefore to the group to which I have extended the name hypsistenocephalic,* to include skulls in which the index exceeds 100.

The three male crania ranged in internal capacity from 1300 c.c. to 1430 c.c., and the mean was 1370 c.c.; in the female E the capacity was 1330 c.c., whilst in D, the sex of which was doubtful, it was 1430 c.c.†

Dusuns. Table I. Plate I.

The name Dusun is given to a tribe in Borneo which occupies the interior of the island from its northern end to as far south as the Dutch territory. Their country is to the north and east of the Muruts, and the Sulus intervene between them and the eastern sea-coast. They are well built, muscular and active. The skin is a light, clear brown, fairer than the Malays of the coast; the hair is black, and is worn by the men hanging down over the shoulders; the eyes also are black. Burbidge says that some have well-cut features, though the Mongolian type of face prevails; the nose is flattened at the root and the nostrils are wide. The teeth are filed and blackened, and the skin is tattooed. The usual stature is 5 feet 4 or 6 inches. The Dusuns are by some authorities considered to possess a strain of Chinese blood, and are less given to head hunting than some of the other tribes. By some authorities the name Ida'an is applied to the Dusuns.

Three skulls presented by Dr Adamson were labelled Dusun, and of these F was further designated Tegahas, a tribe which lives in the hilly country in the interior; G was from the Kinarut district in north-west Borneo; H, Dusun Dyak, Si Labandang, of Ulu Papar, near the source of the river Papar. They were male adults; G and H retained the lower jaw, and in G a large part of the two parietals and of the occipital squama had been apparently sliced off by a sharp weapon. The skulls were not uniform in character. H was much larger and more massive than the others; and

* See my memoir on Scottish Crania, *op. cit.*, vol. xl. pp. 598, 599, 1903, for explanation of the terms metriocephalic and hypsistenocephalic.

† The cranial capacity in this as in my previous memoirs was taken by the method employed and described in my *Challenger Report*, Zoology, part xxix. p. 9, 1884, the accuracy of which has been confirmed since that time by repeated investigations.

Table I.

North Borneo.

	Muruts.					Dusun.			Dalit.	Kweejow.	
						Tegahas.	Kinarut.	Ulu Papar.			
Collection mark,	A.	B.	C.	D.	E.	F.	G.	H.	I.	L.	K.
Age,	Ad.	Ad.	Ad.	Ad.	Adol.	Ad.	Ad.	Ad.	Ad.	Ad.	Youth.
Sex,	M.	M.	M.	F?	F.	M.	M.	M.	M.	M.	...
Cubic capacity,	1380	1300	1430	1430	1330	1270	...	1570	1360	1435	1330
Glabello-occipital length,	180	178	183	175	180ap.	173	180ap.	187	177	180	177
Basi-bregmatic height,	135	133	136	133	...	121	135	138	138	144	131
Vertical Index,	*75·*	*74·7*	*74·3*	*76·*	...	*69·9*	*75·*	*73·8*	*78·*	*80·*	*74·*
Minimum frontal diameter,	91	90	88	88	90	86	91	97	96	96	85
Stephanic diameter,	96	105	103	105	103	97	98	112	107	104	98
Asterionic diameter,	105	107	104	110	98	118	105	110	109	118	96
Greatest parieto-squamous breadth,	133s.	133p.	128s.	136s.	132p.	135s.	130	141	136s.	141	129p.
Cephalic Index,	*73·9*	*74·7*	*69·9*	*77·7*	*73·3*	*78·*	*72·2ap.*	*75·4*	*76·8*	*78·3*	*72·9*
Horizontal circumference,	505	508	508	505	505	499	502	529	508	516	498
Frontal longitudinal arc,	128	128	132	126	130	124	130	125	127	129	127
Parietal ,, ,,	127	127	129	134	125	133	...	128	135	122	131
Occipital ,, ,,	114	105	109	115	106	102	...	139	...	...	...
Total ,, ,,	369	360	370	375	361	358	...	392	...	...	...
Vertical transverse arc,	295	290	296	301	280	285	285	317	309	313	300
Basal transverse diameter,	121	118	121	121	113	114	123	124	125	120	109
Vertical transverse circumference,	416	408	417	422	393	399	408	441	...	433	409
Length of foramen magnum,	38	37	37	36	...	33	33	33	...	...	...
Basi-nasal length,	101	100	104	94	...	90	102	100	100	97	...
Basi-alveolar length,	94	90	102	90	...	91	97	94	96ap.	92	...
Gnathic Index,	*93·1*	*90·*	*98·1*	*95·7*	...	*101·1*	*95·1*	*94·*	*96·*ap.	*94·8*ap.	...
Total longitudinal circumference,	508	497	511	505	...	481	...	525	...	...	...
Interzygomatic breadth,	127	128	131	127	...	127	132	133	139	129	119
Intermalar ,,	117	118	117	115	...	113	117	124	128	123	105
Nasio-mental length,	...	117	106ap.	...	114	...	110	111	...	...	...
Nasio-mental complete facial Index,	...	*91·4*	*80·9*	...	...	...	*83·3*	*83·4*	...	...	...
Nasio-alveolar length,	64	65	68	66	63	62	64	65	66ap.	59	61
Maxillo-facial Index,	*50·4*	*50·7*	*51·9*	*51·9*	...	*49·6*	*48·4*	*48·8*	*47·5*	*45·7*	*51·2*
Nasal height,	52	54	53	50	49	50	54	50	52	46	45
Nasal width,	26	25	26	27	26	26	26	27	24	29	27
Nasal Index,	*50·*	*46·3*	*49·1*	*54·*	*53·1*	*52·*	*48·1*	*54*	*46·*	*63·*	*60·*
Orbital width,	37	39	36	34	37	38	37	37	40	40	33
Orbital height,	35	34	36	31	34	33	34	36	34	35	33
Orbital Index,	*94·6*	*87·2*	*100·*	*91·2*	*91·9*	*86·8*	*91·9*	*97·3*	*85·*	*87·5*	*100·*
Palato-maxillary length,	46	45	51	48	...	48ap.	57	50	49ap.	...	...
Palato-maxillary breadth,	61	63	60	61	62	58	59	64	64	...	...
Palato-maxillary Index,	*132·6*	*140·*	*117·6*	*127·*	...	*120·*	*103·5*	*128·*	*130·*	...	...
Nasio-malar Index,	*111·4*	*108·4*	*109·2*	*111·2*	...	*106·6*	*107·3*	*108·2*	*109·*	*106·*	*112·3*
Cranio-facial Index,	*70·6*	*71·9*	*71·6*	*72·6*	...	*73·4*	*73·3*	*71·1*	*78·5*	*71·7*	*67·2*
Lower jaw. Symphysial height,	...	35	32	...	32	...	29	28	...	...	...
Lower jaw. Coronoid ,,	...	61	55	...	60	...	63	72	...	...	...
Lower jaw. Condyloid ,,	...	59	56	...	58	...	58	69	...	...	...
Lower jaw. Gonio-symphysial length,	...	86	88	...	73	...	89	91	...	...	...
Lower jaw. Inter-gonial width,	...	106	...	...	94	...	103	97	...	...	...
Lower jaw. Breadth of ascending ramus,	...	30	36	...	33	...	44	35	...	...	...

whilst they were smoke-stained, it was not, and evidently had not been suspended in a hut. This man was an ambitious, turbulent native, who had been executed for rebellion.

Norma verticalis.—The cranial outline in H was elongated, somewhat broadly ovoid, the form was dolichocephalic, but the cephalic index, 75·4, slightly exceeded the upper numerical limit of that group. The sagittal line was slightly raised, the vault had a steepish slope downwards to the moderate parietal eminences, below which the side walls were almost vertical. The occipital squama projected behind the inion.

The Tegahas skull was smaller, but the relative breadth was greater, the cranial outline showed a wider ovoid, and the cephalic index, 78, placed the skull in the higher term of the mesaticephali. G, again, was so injured that the form of the vault could not be seen; the length and breadth could only be stated approximately, but the cephalic index was obviously below 75. G was phænozygous, and H and F were cryptozygous.

Norma lateralis.—In all these crania the forehead slightly receded, the glabella and supraorbitals were moderate and distinct from the outer upper orbital borders, above which the frontal was flattened towards the temporal ridge; the nasion was a little depressed, the nasal bridge was not keeled, tended to be flattened from side to side and slightly concave upwards. The nasal bones were well formed, and in H were mesially 27 mm. long. In F and H the parietal arc was longer than the frontal, but in H the occipital arc was the longest, 139 mm., owing to the occipital squama, which was not quite symmetrical, being 105 mm. in its longitudinal diameter. The crania F and G rested behind on the cerebellar fossæ, but in H on the tips of the mastoids.

Norma facialis.—In H a low but smooth ridge separated the floor of the nose from the incisive region; in F and G it was smoothed down and one region was continued into the other; in F the maxillo-nasal spine was faint, in G and H a little stronger. The anterior nares were almost alike in width, and the mean nasal index, 51·3, was mesorhine, though in H, owing to the smaller proportion of nasal height to width, the index was platyrhine: the nasio-malar index ranged from 106·6 to 108·2, and the mean, 107·3, was mesopic.

The face in G and H was low, and the complete index was chamæprosopic, but owing to the nasio-alveolar length the maxillo-facial index was leptoprosopic. The mean gnathic index, computed on the relation of the basi-nasal and basi-alveolar diameters, was 96·7, *i.e.* orthognathous; but in F the incisive part of the upper jaw projected forward, and the index, 101·1, was mesognathous. The interorbital diameter was 23 mm. The orbital aperture was rounded, megaseme, in G and H, but in F the index, 86·8, was mesoseme. The palate had a moderate depth; in F and H the index was brachyuranic, in G hyperdolichuranic. The teeth when present were worn and stained with betel. In the jaws the alveoli were not absorbed; the angles, chins, and muscular markings were distinct in the lower jaws.

The cranial sutures were simple, sutural bones in the lambdoid region were small and sparse, pterion normal. In G and H the styloids were fused with the temporals.

The mean cephalic index in the Dusuns was 75·2 mesaticephalic, and F was in the upper term of that group. The mean basi-bregmatic index was 72·9, metriocephalic. The general dimensions were as follows:—mean length 180 mm., height 131 mm., breadth 135 mm.; the breadth was therefore greater than the height, a character which is usually associated with mesaticephalic and brachycephalic crania. The mean breadth-height index was 97, for in the Tegahas skull the height was only 121 mm. The cranial capacity could be taken only in F and H, which showed great diversity, for F was only 1270 c.c., whilst H, 1570, was above the mean of male Europeans, and was associated with the large cranium and the mental capacity of the individual.

Dalit. Table I.

In Dr Adamson's collection was an adult male skull of a tribe living in the Dalit country, which he stated to be in the interior of North Borneo, bordering on Dutch territory. The skull was smoke-stained and had attached to it a loop of split cane for suspension. The lower jaw was absent.

Lieutenant De Crespigny, R.N., in his memoir on Northern Borneo, published a vocabulary of the Dali Dusun tribe living near the Limbang river, to a member of which tribe this skull may have belonged. There appears indeed to be an association between the Dalits and the Dusuns, as Mr Witti states that many words probably of Dalit origin occur in Dusun speech. South of the Limbang, in the Baram district of Sarawak, is the well-known Mount Dulit, a name which may be associated with the Dalit branch spoken of as Mount Dulit Dusuns.

Norma verticalis.—The cranium was elongated, but owing to the relative breadth the cephalic index, 76·8, placed the skull in the lower term of the mesaticephalic group. The sagittal line was somewhat ridged and the vault sloped steeply down to the parietal eminences, below which the side walls were almost vertical. The parieto-occipital curve was steep and the occipital squama scarcely projected behind a feeble inion. The skull was phænozygous.

Norma lateralis.—The forehead was slightly receding, the glabella and supra-orbital ridges were moderate in size, the frontal was flattened above the external orbital process, and the outer border of the orbit was thickened; the nasion was not depressed, the bridge of the nose was low, tended to be flattened from side to side, and was 25 mm. long in the middle line. The parietal arc was longer than the frontal; the occipital condyls, cerebellar region and mastoids had been injured.

Norma facialis.—A low ridge separated the floor of the nose from the incisive region, the maxillo-nasal spine was moderate. The anterior nares were narrow, and the nasal index, 46, was leptorhine. The nasio-malar index was 109, and therefore mesopic. The canine fossæ were deep. The maxillo-facial index, 47·5, was mesoprosopic, and the interzygomatic breadth was 139 mm. The upper jaw was broken in the incisive region, and the gnathic index was possibly orthognathous. The orbital aperture was

mesoseme, index 85; the interorbital breadth was 23 mm. The hard palate was wide and shallow, and the palato-maxillary index was hyperbrachyuranic; none of the alveoli contained teeth.

The cranial sutures were mostly simple, and those of the vault were undergoing ossification; they had no Wormian bones, and the pterion was normal. The vertical index, 78, was more than the cephalic, and in the height being greater than the breadth the cranium was associated with a character customary in dolichocephalic skulls, and the skull in its breadth-height index, 101·4, was hypsistenocephalic. The internal capacity of the cranium was 1360 c.c.

Kweejow. Table I. Plate III.

Dr Adamson informed me that the tribe which he calls Kweejow or Kijow is found in the interior of North Borneo. He stated that they live on the hills, and that their language differs from that of the other tribes in proximity to them. Obviously little is known of these people, as the name does not occur in Mr Ling Roth's admirable compendium of information on the natives of Sarawak and North Borneo, in Mr C. Hose's memoirs, or in Mr Haddon's work on Head Hunters. In Lieutenant De Crespigny's memoir already quoted is a passage which without doubt refers to this tribe. He says, p. 176, on the Kalias river, near Padas,* live a tribe of people called Köijoes. They differ much in their habits from the neighbouring tribes, and more especially in their food, for where, as among the Muruts and Dusuns, a certain discrimination is exercised in the choice of food, nothing comes amiss to the Köijoes—snakes, worms, and beetles are eaten by them as a matter of course. I received two skulls marked Kweejow; one an adult male without the lower jaw, which weighed 1 lb. 12 ozs. avoir. It was stained deep brown from adherent soot. The other, smoke-stained and without the lower jaw, was that of a youth with the dentition incomplete and the basi-cranial synchondrosis unossified.

Skull L. *Norma verticalis.*—The adult male cranium was broadly ovoid in outline, with a cephalic index 78·3. The vault was not ridged in the sagittal line, and curved at first gently, then more steeply outwards to feeble parietal eminences, below which the side walls were a little convex. The parieto-occipital slope was not steep, and the occipital squama projected much beyond a feeble inion. The skull was phænozygous.

Norma lateralis.—The forehead was receding; the glabella and supraorbital ridges were well-marked and blended with the thickened superior border of the orbit The nasion was depressed, the nasal bones were short, only 18 mm. long in the mid-line, and did not form a keel, so that the root of the nose was flattened from side to side and the profile outline was concave from above downwards. The frontal arc was 7 mm. longer than the parietal. The skull rested behind on the cerebellar part of the occipital bone, which was broken at the foramen magnum.

* The Kalias and Padas rivers are in the western part of North Borneo.

Norma facialis.—A low smooth border separated the floor of the nose from the incisive region, the maxillo-nasal spine was moderate. The anterior nares were wide and the nasal length was small, so that the index, 63, was highly platyrhine. The nasio-malar index in the adult was 106, on the line between platy- and mesopic. The maxillo-facial index, 45·7, was mesoprosopic. The alveolar border of the upper jaw was broken and the index was possibly orthognathous. The upper and outer borders of the orbit were thick; the aperture, 87·5, was mesoseme. The hard palate was wide and shallow, all the teeth had been lost. The projection of the glabella and supra-orbital ridges, the depressed nasion, the short nose and wide nostrils gave to the face a forbidding aspect.

The cranial sutures were simple and to a large extent ossified. No Wormian bones were observed, but a large left epipteric was present. The cephalic index, 78·3, was in the higher term of the mesaticephalic group, the height of the cranium was greater than the breadth, the vertical index of the skull, 80, was hypsicephalic. The internal capacity of the cranium was 1435 c.c.

Skull K.—The youth's skull differed materially from that of the adult. It was definitely dolichocephalic, with the cephalic index 72·9, and the height was more than the breadth; the nasio-malar index, 112·3, was prosopic. Although the dentition was incomplete, the face was actually longer than in the skull of the adult, and the maxillo-facial index, 51·2, was leptoprosopic; the orbit was rounded with a megaseme index, 100, and the nasal index, 60, as in the adult, was platyrhine. The skull was smoke-stained, and had doubtless been suspended in a house as a war trophy, for the head-hunting tribes do not scruple to make victims of women and children; possibly the skull was not a Kweejow, but had belonged to a neighbouring dolichocephalic tribe. The cranial capacity was 1330 c.c.

Dayaks.

The term Dyak is sometimes incorrectly used by travellers to designate generally the wild people of Borneo. Mr Everitt contends that it should only be applied to the tribes who themselves use it as their distinctive appellation. In this sense it seems to be employed by the resident officials in Sarawak and North Borneo. The late Sir James Brooke used the word as properly applicable to wild people "inhabiting parts of the north-western coasts and the mountains of the interior," and he divided them into two groups, Land Dyaks and Sea Dyaks. At one time the difference between them was regarded as one of circumstance only, and that they were essentially the same people. More recent inquiries have led to the belief that these groups differ from each other in many particulars.

Land Dyaks. Table II. Plate II.

The Land Dayaks chiefly occupy the Sadong and Sarawak river districts and extend into Dutch Borneo. They are described as having the skin of a reddish or yellowish brown colour, the hair black and worn generally long, the eyes black, the nose flattened at the bridge and wide at the nostrils; the face broad; in stature the men range from 5 feet 2 inches to 5 feet 5 inches, rarely 5 feet 7 inches, whilst the women are from 4 feet 6 inches to 5 feet. They file the teeth, which are stained of a black colour. They are head hunters, and the heads are kept in houses specially built for their reception, in which the bachelors live.

Dr Adamson sent me the skull of an adult male Land Dayak from Sarawak, which was not smoke-stained and had no loops of cane attached to it. The lower jaw was absent.

Norma verticalis.—The skull was somewhat elongated in relation to the breadth, and the cephalic index, 76·3, was in the lower term of the mesaticephali. The vault was a little ridged in the sagittal line and had a marked downward slope to the moderate parietal eminence, below which the side walls were almost vertical. The parieto-occipital slope was not abrupt and the occipital squama scarcely bulged behind the inion. The skull was phænozygous.

Norma lateralis.—The forehead receded slightly, the glabella and supraorbitals were moderate in projection, and the latter did not blend with the outer upper border of the orbit; the frontal was flattened above the external orbital process. The nasion was scarcely depressed. The parietal longitudinal arc was the longest, the occipital the shortest. The skull rested behind on the cerebellar region of the occipital bone.

Norma facialis.—The nasal floor was separated from the incisive region by a low ridge, the incisive and canine fossæ were deep, the maxillo-nasal spine was feeble. The anterior nares were moderately wide and the index, 49·1, was mesorhine. The mid-length of the nasal bones was 25 mm. The nasio-malar index was 106·1 and the face was mesopic. The maxillo-facial index, 52·4, showed a relatively narrow, leptoprosopic face, and the interzygomatic breadth was 132 mm. The upper jaw was orthognathous. The orbital aperture was round and the megaseme index was 100. The hard palate was shallow, the palato-maxillary index was hyperbrachyuranic. The teeth were slightly worn and not stained with betel.

The sutures of the cranial vault were simple and were to some extent obliterated. The right half of the occipital squama formed a large triquetral bone, partially fused with the rest of the squama. The pterion was normal. No special variations were seen at the base of the skull.

Although the cephalic index, 76·3, was in the lower term of the mesaticephalic group, the general form of the cranium was dolichocephalic;* the vertical index, 75·1, hypsicephalic, was less than the cephalic, and the breadth and height index was 98. The internal capacity of the cranium was 1230 c.c.

*Mr Haddon states, *op. cit.*, p. 322, that the cephalic index of the skull of a Land Dyak in the Cambridge Museum was 71·3.

Sea Dyaks. Table II. Plate II.

The Sea Dyaks occupy Sarawak to the east of the Land Dyaks; they have settled on the banks of the Rejang, Kalakah, Saribas and Batang-Lupar rivers, with their tributaries, and they are found also in Dutch Borneo. Mr Maxwell states that they are more stoutly built than the Land Dyaks. The skin is a rich brown, the hair is long, jet black and flowing; the eyes are black; the nose is short and upturned at the tip. The women are not so dark as the men and the skin has a yellowish tint. The average stature of the men is about 5 ft. 3 in., though occasionally it reaches 5 ft. 7 in. They exceed the Malays in height and have graceful figures. They file the teeth and stain them black. They are head hunters. Tattooing is not universally practised. Mr Haddon adopts the name Iban in substitution for Sea Dyak, and he gives the following physical characters:—average stature 5 ft. $2\frac{1}{2}$ in.; broad head, average cephalic index 83; skin darker than among the inland tribes; long, slightly wavy, black hair, showing a reddish tinge in certain lights; the people, though short, are active.

The skull of an adult male Sea Dyak was in the collection made by Dr Adamson. It was not smoke-stained, nor was a loop of cane attached to it for purpose of suspension. It was injured in the left parietal and squamous regions, and the lower jaw had not been preserved.

Norma verticalis.—The cranium was broadly ovoid in outline, and the cephalic index, 78·5, was in the upper term of the mesaticephalic group. The vault was faintly keeled, and it sloped definitely down to the parietal eminences, below which the side walls bulged a little. The parieto-occipital slope was steep, though not vertical, and it was oblique to the left, probably from artificial flattening. The skull was phænozygous.

Norma lateralis.—The forehead was somewhat retreating; the glabella and supra-orbitals were well marked; the outer part of the upper border of the orbit was thickened but distinct from the supraorbital process, and the corresponding part of the frontal bone was flattened. The nasion was slightly depressed; the bridge of the nose was broken, but obviously had only slightly projected, and had been somewhat flattened from side to side. The frontal longitudinal arc was the longest, the occipital was the shortest. The skull rested behind on the mastoids.

Norma facialis.—The floor of the nose was separated from the incisive region by a low ridge; the maxillo-nasal spine was short. The anterior nares were relatively wide, and the nasal index, 50·9, was mesorhine. The canine and incisive fossæ were moderately deep. The nasio-malar index was 108·9 and mesopic. The maxillo-facial index, 51·8, was narrow or leptoprosopic, although the interzygomatic breadth, which gave width to the face, was 139 mm. The upper jaw showed alveolar prognathism and the gnathic index was highly mesognathous. The interorbital breadth was 26 mm., the orbital aperture was nearly equal in its two dimensions and the index was megaseme. The hard palate was moderate in depth and the palato-maxillary index, 116·3, was brachyuranic. The teeth had not been preserved.

TABLE II.

	Borneo.				Malays.	
	Land Dyak, Sarawak.	Sea Dyak.	Tali, Bajau, Brunei.	Bajau.	Perak.	Challenger.
Collection mark,	O.	P.	M.	N.	P	C.
Age,	Ad.	Ad.	Ad.	Ad.	Ad.	Ad.
Sex,	M.	M.	M.	M?	M.	M.
Cubic capacity,	1235	...	1350	1180	1515	1515
Glabello-occipital length,	173	172	164	154	173	163
Basi-bregmatic height,	130	140	137	124	141	145
Vertical Index,	*75·1*	*81·4*	*83·5*	*80·5*	*81·5*	*89·*
Minimum frontal diameter,	93	94	86	92	94	96
Stephanic diameter,	95	101	103	92	113	121
Asterionic diameter,	118	118	101	103	106	107
Greatest parieto-squamous breadth,	132s.	135s.	136p.	137s.	140	151
Cephalic Index,	*76·3*	*78·5*	*82·9*	*89·*	*80·9*	*92·6*
Horizontal circumference,	496	496	478	470	505	508
Frontal longitudinal arc,	116	128	123	111	126	127
Parietal „ „	120	124	129	115	127	123
Occipital, „ „	111	103	109	96	116	111
Total, „ „	347	355	361	322	369	361
Vertical transverse arc,	284	300	300	287	312	330
Basal transverse diameter,	122	130	115	125	126	135
Vertical transverse circumference,	406	430	415	412	438	468
Length of foramen magnum,	40	37	37	36	34	35
Basi-nasal length,	99	102	96	90	104	98
Basi-alveolar length,	90	100	93	92	104	92
Gnathic Index,	*90·9*	*98·*	*96·9*	*102·2*	*100*	*93·8*
Total longitudinal circumference,	486	494	494	448	507	494
Interzygomatic breadth,	132	139	123	129	136	145
Intermalar,	121	127	114	114	126	128
Nasio-mental length,	...	...	114	...	115	127
Nasio-mental complete facial Index,	...	...	*92·6*	...	*84·5*	*87·6*
Nasio-alveolar length,	69	72	68	64	68	74
Maxillo-facial Index,	*52·4*	*51·8*	*55·6*	*49·6*	*50*	*51*
Nasal height,	53	53	50	48	53	58
Nasal width,	26	27	24	26	26	25
Nasal Index,	*49·1*	*50·9*	*48·*	*54·2*	*49·1*	*43·1*
Orbital width,	37	39	38	36	35	41
Orbital height,	37	37	33	36	32	38
Orbital Index,	*100·*	*94·9*	*86·8*	*100·*	*91·4*	*92·7*
Palato-maxillary length,	49	55	54	51	55	51
Palato-maxillary breadth,	66	64	68	62	67	65
Palato-maxillary Index,	*134·6*	*116·3*	*125·9*	*121·5*	*120·1*	*127·4*
Nasio-malar Index,	*106·1*	*108·9*	*107·5*	*103·*	*108·1*	*106·8*
Cranio-facial „	*76·3*	*80·8*	*75·*	*83·8*	*78·6*	*89·0*
Lower jaw. Symphysial height,	...	34	...	...	34	31
Lower jaw. Coronoid, „	...	66	...	...	64	67
Lower jaw. Condyloid, „	...	66	...	...	63	65
Lower jaw. Gonio-symphysial length,	...	85	...	...	87	98
Lower jaw. Inter-gonial width,	...	99	...	...	101	106
Lower jaw. Breadth of ascending ramus,	...	33	...	...	41	45

The cranial sutures were simple and unossified; a few small Wormian bones were in the lambdoid and the right pterion had an epipteric bone; the jugal processes were tuberculated. The inion was strong and dependent, and the muscular ridges were pronounced. The cephalic index, 78·5, in the higher term of the mesaticephalic group, approached the brachycephali; the vertical index, 81·4, hypsicephalic, was greater than the cephalic. The internal capacity could not be accurately obtained, owing to the cranium being injured.

Bajaus or Sea Gypsies. Table II. Plates III., V.

The Sea Gypsies, named Bajau, Bajow, Baju, or Badjoo, are wandering fishermen, who live either in boats or in houses raised on piles near the mouths of rivers in Borneo and Celebes. They are said by Sir Hugh Low to have come originally from Johore on the Straits of Malacca.* Sir Spencer St John described them as short in stature, slight and active, with pinched small faces, low foreheads and bright eyes. They wear the hair tied in a knot on the front of the head. They practise tattooing.

Two adult skulls presented by Dr Adamson were labelled Bajau or Bajow. The larger, M, that of Mohammed Tali, was from Brunei, a small native State intervening between North Borneo and Sarawak. The man was said to have been muscular, about 5 ft. 4 in. in stature, with dark skin, coarse long black hair, brown eyes, nose flattened at the bridge, lips moderately thick. He was a well-known cattle thief, and was shot whilst defending a fort which he had built. The smaller skull, N, was marked Malay trader; it may have been that of a man, though the sex characters were not very definite; the wisdoms had not erupted, but the basi-cranial synchondrosis was ossified. The skulls were not smoke-stained, and M retained the lower jaw.

Norma verticalis.—The crania were rounded in outline; that of Tali was brachycephalic, cephalic index 82·9, whilst N was hyperbrachycephalic, index 89. The high index was due to the glabello-occipital diameter, in the mean 159 mm., being much less than in the other native skulls from Borneo, whilst the greatest breadth was about the average. The crania were not keeled in the sagittal line; the vault sloped gently downwards to the prominent parietal eminences, below which the side walls were not quite vertical. In M the parieto-occipital slope was almost vertical, though with a slight obliquity to the left, and the back of the skull was flattened, apparently by artificial pressure, so that it was almost in the same vertical plane as the inion. N had a similar parieto-occipital flattening, though without any obliquity. Both were phænozygous.

Norma lateralis.—The forehead was almost vertical, the glabella and supraorbital ridges were feeble and distinct from the upper border of the orbit; the nasion was not depressed. The bridge of the nose was faintly keeled with a shallow concavity forward. In M the nasal bones were 17 mm. long in the mesial line, in N only 13 mm. and very

* They are well known at the present time as frequenting the straits between the islands of the Johore Archipelago, where they bear the name Sea-Jakun or Orang Laut. They have been regarded as an aboriginal, primitive Malay sea tribe. *Vide* the works of Nelson Annandale, Rudolf Martin, and Messrs Skeat and Blagden.

narrow. In both, the occipital longitudinal arc was the shortest, the parietal the longest. The skulls rested behind on the cerebellar fossæ of the occipital.

Norma facialis.—The floor of the nose was separated by a low ridge from the incisive region; the maxillo-nasal spine was moderate, the incisive fossæ were moderate, and in N the canines were deep. In M the anterior nares were relatively narrow, the nasal index, 48, being leptorhine: in N the index, 54·2, was platyrhine. The nasio-malar index ranged from 103 to 107·5, and the mean was 105·2, platyopic.

The complete facial and maxillo-facial indices were computed in M and seen to be leptoprosopic, and in N the maxillo-facial was almost in the same group; the proportions of length and breadth gave a narrow-faced skull. In M the incisive region projected forwards and produced an alveolar prognathism, although the gnathic index, 96·9, as determined by FLOWER's method, placed it in the orthognathic group; in N the index, 102·2, was mesognathous. In M the orbital index, 86·8, was mesoseme, but in N the aperture was rounded and the index, 100, megaseme. In both skulls the hard palate was moderate in depth, and the palato-maxillary index was hyperbrachyuranic. The teeth were betel-stained; the crowns were much flattened in M, but less so in N. The lower jaw in M had strong masculine characters.

The cranial sutures were simple and unossified, without Wormian bones in the lambdoid; the right jugal process in M and both jugals in N had a short pointed paracondylar process. In M the styloid process was ossified to the temporal, and there was a right epipteric bone. In M the basi-bregmatic height was 1 mm. more than the greatest breadth of the cranium, but in N it was 13 mm. less: the mean cephalic index, 85·9, of the two crania exceeded the mean vertical index, 82, hypsicephalic, which is the rule in brachycephalic skulls, and the mean breadth-height index was 95·2. The internal capacity of the cranium of Tali was 1350 c.c., but that of N was only 1180 c.c., a capacity which is more in accordance with that of the female than the male skull.

MALAYS. TABLE II. PLATE IV.

The Museum does not contain any Malay skulls from Borneo with which to contrast the skulls above described. Several specimens are indeed marked Malay without any further information, but as their history is obscure I do not dwell on them. Two Malay skulls which have a definite history are worthy of description. One, from a man who had died in hospital in Calcutta, was given to me more than twenty years ago, along with the other bones of the skeleton, by Lieut.-Col. DOUGLAS D. CUNNINGHAM, M.D., F.R.S., and the skeleton, the skull excepted, was described in my memoir in the *Challenger Reports.** The other was presented to me, along with the pelvis, in 1889 by the late Dr WM. DUNCAN SCOTT, medical officer in Perak, Malay Peninsula. They were parts of the skeleton of a male Malay, said to be about 26 years old, who

* Zoology, part xlvii., 1886,—part ii., the Bones of the Skeleton.

had lived near the junction of the Perak and Chenderiang rivers. The lower jaw was present. These skulls are marked P and C in Table II.

Norma verticalis.—The cranial outline in P was broadly ovoid, the cephalic index, 80·9, was brachycephalic; in C the outline was rounded, and the index, 92·6, was hyperbrachycephalic. They had no sagittal ridge, and the slope of the vault to the parietal eminences was moderate, below which the side walls were a little convex. The parieto-occipital slope in P was steep, and the occipital squama projected behind the inion, possibly there was slight occipital flattening; in C the slope of the parieto-occipital region was vertical from the parietal foramina, and the artificial flattening was so marked that the occipital squama did not project behind the inion. The skulls were cryptozygous.

Norma lateralis. — In P the forehead was almost vertical, in C it somewhat receded; in both the frontal eminences were distinct, and the bone was flattened above the upper border and external process of the orbit; the glabella and supraorbital ridges were moderate, and the nasion was slightly depressed; the nasal bridge was feeble, the profile outline was concave; in C the mid-nasal length was 32 mm., in P, with a deeper concavity, 26 mm. The occipital longitudinal arc was the shortest, the frontal and parietal were almost equal. The skulls rested behind on the mastoids.

Norma facialis.—The floor of the nose was smoothed down into the incisive region; the maxillo-nasal spine was moderate; the incisive and canine fossæ were moderate: in P the nasal index, 49·1, was mesorhine, in C the nasal height in relation to the width was greater and the index, 43, was leptorhine; the nasio-malar indices showed the profile of the nose to be mesopic. The complete facial index in P was chamæprosopic; in C mesoprosopic, in which the interzygomatic diameter was 145 mm.; in both the maxillo-facial index was leptoprosopic. The gnathic index, as determined by FLOWER's method in P, was mesognathous, in C orthognathous, though to the eye the upper jaw in C had a forward projection. The orbital aperture was rounded, megaseme; the interorbital diameter was 26 and 24 mm. respectively; in P the supraorbital foramina had complete bony walls. The palatal arch in P was 18 mm. deep opposite the second molar, in C it was shallower; in both the palato-maxillary index was hyperbrachyuranic. In P the teeth had all erupted except the upper wisdoms, the crowns were worn and flattened by use, especially the incisors, the flattened biting edges of which were in contact with each other when the mouth was closed.* In C the crowns were also much worn, though the edges of the incisors were not so closely adapted as in P; the teeth were deeply stained. The lower jaw was strong, the chin was square and projecting, the angle was well defined.

The cranial sutures were simple and no sutural bones were present. The mastoids and the temporal curved lines were well marked, the inion and occipital curved lines were feeble; in P the styloids were ossified to the temporals, and each vaginal process

* I may refer to my paper on the relations of the Dentary Arcades in the Crania of Australian Aborigines (*Journ. of Anat. and Phys.*, vol. xxv. p. 461, 1891) for an account of this character in certain races. I may state that I have twice seen the adaptation of the biting edges of the incisors in Scottish students of my anatomical class.

was prolonged into a broad curved plate; in both the jugals were tuberculated. In P the basi-bregmatic diameter exceeded the greatest breadth by 1 mm., and the vertical index, 81·5, hypsicephalic, was slightly more than the cephalic index, 80·9; in C the cephalic index, 92·6, exceeded the vertical, 89, as is customary in brachycephali; and the mean breadth-height index was 90·5. The cranial capacity in each skull, as determined by my method, was 1515 c.c., a volume which exceeded somewhat the mean capacity in Europeans of the male sex.* Each skull was brachycephalic, *i.e.* the length-breadth index was 80 and upwards; the term therefore includes both the sub-brachycephalic and brachycephalic groups of Paul Broca. This type of head is without doubt the form found in the pure Malay, and when we see in Museums skulls, either dolichocephalic or approximating thereto, labelled Malay, we may regard them as not of the pure race, but either a product of cross-breeding, or not properly identified.

Pelvis.—The skull from Perak was accompanied by the bones of the pelvis, which I compared, after being articulated, with the pelvis of the male Malay described by me in the *Challenger Reports* a number of years ago.† For convenience of reference I give in the following table the chief measurements of the two specimens:—

Measurements of Pelves of Malays.

	Perak.	*Challenger.*
Breadth,	256 mm.	235 mm.
Height,	198	200
Breadth-Height Index,	*77·1*	*85*
Between ant. sup. iliac spines,	240	193
„ post. „ „ „	81	69
Vertical diameter obturator foramen,	51	55
Transverse „ „ „	34	34
Obturator Index,	*66·6*	*62*
Subpubic angle,	65°	76°
Transverse diameter pelvic brim,	122	110
Conjugate, „ „ „	104	116
Pelvic or Brim Index,	*85·2*	*105*
Between inner borders ischial tubera,	77	109
Depth of pubic symphysis,	38	42
„ pelvic cavity,	85	100
Length of sacrum,	111	112
Breadth „	107	106
Sacral Index,	*96·4*	*95*

The Perak pelvis was broader and the muscular processes and ridges were somewhat stronger than in the pelvis described in the *Challenger Reports.* The iliac fossæ were not translucent, and the alæ were more expanded and more directed outwards than in the Challenger specimen, in which the alæ approached in their direction nearer to the vertical. In the Perak pelvis the subpubic angle was 65°, and was more in accord with

* The mean capacity of the crania of seventy-three Scotsmen, taken by the same method, was 1478 c.c. See my memoir on Scottish Crania in *Trans. Roy. Soc. Edin.*, vol. xl. p. 601, 1903. The capacity measured by the method of Broca is in excess of the actual capacity.

† Zoology, part xlii. p. 18, 1886.

the customary width of the angle in the male than was the angle, 76°, of the Challenger specimen. The shape of the brim of the pelvis was not uniform; in the Perak specimen the transverse diameter was much in excess of the conjugate, the form of the inlet was ovoid transversely, and the index was platypellic; whilst in the Challenger example the conjugate exceeded the transverse diameter, the brim was ovoid antero-posteriorly, and the index was dolichopellic. On the other hand, the intertuberal diameter of the pelvic outlet and the depth of the true pelvis were much less in the Perak than in the Challenger examples. The length of the sacrum measured in a straight line and the breadth of the bone at the base were almost alike in the two specimens, and the sacral index was dolichohieric. The first coccygeal vertebra was not ankylosed to the sacrum. The præ-auricular sulcus was a shallow vertical groove; the pectineal line was not raised into a sharp ridge, and the pubic spine was prominent.

The University Museum has recently received two male adult Malay skulls collected by Messrs Annandale and Robinson in their expedition to the Malay Peninsula in 1901–02. They have been described in detail by Nelson Annandale, D.Sc., in "Fasciculi Malayenses."* One, No. 21, was from Jambu, Jhering; the other, No. 22, a Kalantan Malay, was from the town of Patani. In No. 21 the cranium was "square shaped" in outline, the parieto-occipital slope was abrupt and unsymmetrical, the cephalic index 85·9, the skull cryptozygous. In No. 22 the cranium was broadly ovoid, the parieto-occipital slope not quite so abrupt, the cephalic index 79, the skull phænozygous. The vertical index in No. 21 was 85·2, in No. 22, 75·5, and in each, as is so common in brachycephalic skulls, the breadth was greater than the height. In both, the nose was leptorhine, the upper jaw projected forward, the palato-maxillary region dolichuranic, and the complete facial index chamæprosopic. In No. 21 the orbit was microseme and in No. 22 mesoseme.†

The Jambu skull had an incomplete skeleton, the pelvis of which possessed male characters and was a little smaller than the pelvis in my specimen described in the *Challenger Reports*. The conjugate diameter of the brim, 98 mm., was almost equal to the transverse, 100 mm., and the pelvic index, as in the Challenger specimen, was dolichopellic. The length of the sacrum in a direct line was 102 mm., and along the curve 110 mm.; the maximum breadth was 98 mm.; the sacral index, 96·1, was dolichohieric, as in the Challenger and Perak pelves. The subpubic angle was 60°.

* *Anthropology*, part ii. (*a*) p. 93, 1904.

† The most recent information on the physical characters of the Malays is to be found in Nelson Annandale's description in "Fasciculi Malayenses," 1904; Rudolf Martin, *Die Inlandstämme der Malayischen Halbinsel*, Jena, 1905; W. W. Skeat and C. O. Blagden, *Pagan Races of the Malay Peninsula*, London, 1906.

Glogner, "Sieben malaische Schädel," *Verhandl. der Berliner Gesells. für Anth.*, p. 378, 1892.

Kohlbrügge, "Anthrop. Beobacht. aus dem Malayische Archipelago," *Verh. der Berliner Gesells. für Anth.*, p. 396, 1900.

GENERAL OBSERVATIONS ON BORNEO CRANIA.

Owing to the limitation in number of the skulls and the restricted area in the island in which they were collected, the material at my disposal is not adequate to permit a comprehensive survey, based on my own observations, of the craniology of the natives of the whole of Borneo. Sufficient have, however, been examined to enable me to state that in North Borneo, Brunei and Sarawak the crania of the natives are not uniform in character, but show diversities in form and proportion, which justify the conclusion that the island is inhabited by different races. Attempts have been made from time to time, amongst others, by MM. De Quatrefages and Hamy, Mr C. Hose and the naturalists who have studied the people of Sarawak along with him, and by Nieuwenhuis and Kohlbrügge, from observations on the people of Dutch Borneo, to differentiate the several races, the period when they populated the island, and the order of their immigration.

In an ethnographical survey of the great islands in the Malay Archipelago one cannot overlook the possibility of the presence in them of a Negrito element, characterised by pigmy stature, black skin, and short woolly black hair, either pure or cross-bred with another race or races. The Semangs in the adjacent Malay Peninsula, the Mincopies of the Andaman Islands, and the Aëta Pigmies in some of the Philippine Islands are well-known examples of Negritos occupying countries in more or less close proximity to the great islands of the Archipelago.

In Borneo itself apparently the most primitive people are the Punans, or, to employ the name given by Bock, as used in south-east Borneo, the Orang Poonans. They are the Forest people who live in the jungles and dense forests in the mountains at the head waters of the big rivers. Hose and Bock regard them as the aboriginal inhabitants; they do not cultivate the soil, but live by hunting and on the products of the jungles, and are nomadic in their habits. If a Negrito element existed one would expect it to be met with in these tribes. Bock described those seen by him in Dutch territory as yellow in colour, the women being much lighter than the men, the hair long and black and the stature moderate, all of which do not conform with Negrito characters. Hose recognises their fair skin and also large-boned, strong physique. Haddon says that the Punans are broad-headed, with an average cephalic index 81.

The physical characters therefore in important particulars do not accord with those of the Negritos, although, if Haddon's statement be correct, they approximate to them in the relations of the breadth to the length of the head. It should be stated that the Punans are not head hunters and do not build houses. There is also no evidence that the Ukits, also nomadic, who live in the Kayan country in Sarawak, are to be associated with the Negritos; probably they are a branch of the Punans.

The river valleys and the adjoining hill ranges in Borneo are peopled by tribes bearing various names, *e.g.* Sebop, Melanau, Kadayan, Kalabit, Ot Danum, Ulu

Ajar, Land Dyaks, Muruts, Dusuns, Dalits, etc. HOSE, SHELFORD and HADDON have grouped these tribes together by the general name Kalamantans, a term derived from the natives of Sarawak, who give the name Pulo Kalamantan to Borneo. HOSE and SHELFORD group the Punans with the Kalamantans, although the latter are agriculturists and have a higher social organisation than the nomadic Punans. The Kalamantans had probably migrated into Borneo, either from the Asiatic Continent or from the groups of islands to the eastward, at some unknown period.

The observations recorded in the earlier pages of this memoir enable one to speak of the cranial characters of the Muruts, Dusuns, the Dalit Dusun, who form so considerable a proportion of the inland population of North Borneo, and also the Land Dyak from Sarawak. The cephalic index in the ten skulls examined ranged from 69·9 in a Murut to 78 in the Tegahas Dusun, and the mean of the series was 74·8. Five of the skulls had the index below 75, and were distinctly dolichocephalic in form and proportions; in the other five the greater relative breadth placed them in the mesaticephalic group, and of these three were below 77. In four specimens the vertical index exceeded the cephalic, in one these indices were equal, in four the cephalic index was the greater; in the entire series the mean vertical index was 74·6, fractionally lower than the mean cephalic, and not showing so large a difference as is customary in dolichocephalic crania. The nasal index ranged from 46 to 54; three were platyrhine, two were leptorhine, five were mesorhine; the mean of the entire series, 50, was mesorhine. The gnathic index in nine skulls, as determined by FLOWER's method, ranged from 90 to 101; seven were orthognathous, two were mesognathous, and the mean of the series, 94·8, was orthognathous.

The interzygomatic breadth ranged from 127 to 139 mm. and the mean was 130·6 mm.; the nasio-alveolar length ranged from 62 to 69 mm. and the mean was 65·2; the maxillo-facial index ranged from 47·5 to 52·4; no specimen was chamæprosopic, four were mesoprosopic, the majority were leptoprosopic, with relatively narrow faces, to which group the mean index of the series, 50, is to be referred. The nasio-malar index ranged from 106·1 to 111·4; no specimen was platyopic or flat-faced, *i.e.* with the index below 106, two were pro-opic, index above 110, the majority were mesopic, which was the mean index, 108·6, of the series, the profile of the nose having a moderate projection. The orbital index ranged from 85 to 100; no skull was microseme, three were mesoseme, seven were megaseme; the mean of the series, 92·5, was also megaseme, with rounded orbits. The palato-maxillary index ranged from 103·5 to 140 mm.; only one specimen had the arch long in relation to the breadth, dolichuranic; the rest had relatively wide arches and were brachy- or hyperbrachyuranic.

From this summary of the characters of the skulls in these Kalamantan tribes it may be stated that they were dolichocephalic or approximated thereto; whilst in some the height was more than the breadth, in others the reverse was seen, but in the crania as a whole the mean height and breadth were almost equal. The nose was moderately wide at the anterior nares and not greatly flattened at the bridge. The face was not

low and of moderate width; the upper jaw was not very projecting; the orbits were rounded, and the palate had, as a rule, a wide and shallow arch.

Since the time of ANDERS RETZIUS anthropologists have recognised the importance of determining the relation of the length to the breadth of the cranium in different races of men and have for many years expressed these relations numerically by the cephalic index. Attention has been subsequently called by J. KOLLMANN to the relation between the length and breadth of the face, and he has employed the term leptoprosopic to express a face long and narrow in relation to its breadth, and chamæprosopic for a face relatively low and broad. In my memoir on the Craniology of the People of Scotland * I have suggested an intermediate or mesoprosopic group between the two extreme forms.

Little attention, however, seems to have been given to the relation between the length of the cranium and the breadth of the face, and to distinguish if differences in this relation existed in dolichocephalic when contrasted with brachycephalic crania. A numerical expression of the relation between cranial length and facial breadth may be obtained and a *cranio-facial index* computed by the following formula $\frac{\textit{interzygomatic breadth} \times 100}{\textit{maximum length}}$, the length being regarded as = 100.

In the nine crania of the Kalamantan group, in which both the glabello-occipital and the interzygomatic diameters were measured, the cranio-facial index varied from 70·6 in a Murut to 78·5 in the Dalit skull, and the mean was 73·2. It would seem, therefore, that in these people a face relatively high and narrow was associated with a cranium relatively long and narrow. The two skulls with the highest cranio-facial index, 76·3 and 78·5 respectively, had cranial proportions in which the breadth was somewhat greater in relation to the length and the skulls were in the lower term of the mesaticephalic group.

I have not, in the summary of this group, included the two Kweejow skulls, for though both were marked as being of the same tribe, the young skull was definitely dolichocephalic, whilst the adult was in the higher term of the mesaticephalic group. If the proportions shown by the youth's cranium may be regarded as characteristic of the tribe, it doubtless should be associated with the dolichocephalic Kalamantans; but if the mesaticephalic skull more nearly represented the customary proportions, then possibly the tribal character was due to a cross between the Kalamantan and a race the crania of which possessed brachycephalic proportions. The low cranio-facial index, 67·2, of the Kweejow youth is associated with the imperfect development of the face and the dental arcades.

Messrs HOSE, SHELFORD and HADDON have described in Sarawak tribes named Kenyahs and Kayans, and KOHLBRÜGGE and NIEUWENHUIS have also recognised Kayans in Dutch territory. They are believed to have entered Borneo by the rivers which join the sea on the east and south-east coasts, at a period subsequent to the immigration of the Kalamantans, and gradually to have penetrated westward into Sarawak, which

* *Op. cit.*, p. 606. See footnote to this memoir, p. 783.

they occupied in the region midway between the coast and the highlands of the interior. They are said to have low brachycephalic heads, but no crania of these tribes have come under my observation.

The coast line of Borneo is peopled by Sea Dyaks, Bajaus or Sea Gypsies, and Malays. To all appearance the coast tribes had settled at a period subsequent to the immigration of the Kalamantans, Kenyahs and Kayans. Unfortunately the number of specimens of the people of the coast under examination was too small to enable me to formulate a wide generalisation. Mr HADDON states that the Sea Dyaks have broad heads, with a mean cephalic index 83. The index of my only specimen of the skull was 78·5, approaching the brachycephalic in its proportions, and thereby distinguished from the dolichocephalic Kalamantans, in which group the Land Dyaks have been included.

The two skulls of the Bajaus at once strike the observer as distinct in type from the Kalamantan Muruts and Dusuns. They were on a smaller scale, especially in length, the parieto-occipital slope was so steep as to be almost vertical, and the flattened form of the occiput was obviously in part at least due to pressure applied during infancy. Both skulls were brachycephalic, one indeed was hyperbrachycephalic, the artificial flattening having doubtless contributed in part to the production of an antero-posterior shortening of the cranium.

If the Sea Dyak and the two Bajau skulls be classed as a group, the mean cephalic index was 83·4, brachycephalic, and the mean vertical index was 81·8. The nasal index ranged from 48 to 54·2, and the mean, 51, was mesorhine; the interzygomatic breadth ranged from 123 to 139 mm., and the mean was 130·3 mm.; the nasio-alveolar length ranged from 64 mm. to 72, the mean was 68 mm.; the mean maxillo-facial index, 52·3, was leptoprosopic: the nasio-malar index ranged from 103 to 108·9, and the mean was 106·4, mesopic: the gnathic index ranged from 96·9 to 102·2, and the mean was 99, mesognathous: the orbital index ranged from 86·8 to 100, and the mean was 93·9, megaseme: the palato-maxillary index ranged from 116·3 to 125·9, and the mean was 121·2, hyperbrachyuranic. The coast tribes therefore may be said to be short- or round-headed; the nose moderately wide at the anterior nares and not projecting at the bridge; the face long in relation to the breadth; the upper jaw moderately projecting; the orbits rounded, the palate shallow and with a wide arch.

The two Malay skulls described in this memoir were brachycephalic, with a mean cephalic index 86·7, and with a mean vertical index 85·2; the mean nasal index, 46·1, was leptorhine; the mean interzygomatic breadth was 140·5, the mean nasio-alveolar length was 71, and the maxillo-facial index, 50·5, was leptoprosopic; the mean nasio-malar index, 107·4, was mesopic; the mean gnathic index, 96·9, orthognathous; the mean orbital index, 92, megaseme; the mean palato-maxillary, 123·7, hyperbrachyuranic. In most of these indices the Malays corresponded with the Sea Dyaks and Bajaus.

The cranio-facial index was computed in these brachycephalic skulls. In the Bajau M, marked Tali, it was only 75. In N it was 83·8 and in the Sea Dyak 80·8, materially

higher in these two skulls than in the dolichocephalic Kalamantans, and approximating to the two brachycephalic Malays, in which the mean cranio-facial index was 83·8. The modifications in the cranio-facial index recorded in this memoir point to the association of relatively long heads with narrow faces, and relatively broad heads with wide faces. The cranial characters generally expressed an affinity between the Sea Dyaks, Sea Gypsies and Malays, and pointed in all probability to a common descent. Their immigration from the Malay Peninsula, or from the great islands of the Malay Archipelago, had in all probability been at different periods; and some amount of cross-breeding with the older Kalamantan inhabitants had not unlikely taken place.

Several Museums contain collections of skulls from Borneo which usually do not have tribal names attached to them, whilst in many cases the precise locality from which they came is not definitely specified. In the great collection formed by Barnard Davis, now added to the Museum of the London College of Surgeons, twenty-three skulls said to be from the Island of Borneo * are entered by the general name "Dyak" without any tribal designation. They are all apparently from Dutch territory, and several are elaborately decorated. Davis has recorded the length-breadth (cephalic) index in twenty-one of these skulls. In six the index was 80 and upwards, and of these five were from localities on the coasts; for example, two were from Banjermassin, one from Koesan near Pagottan also on the south, another from the south-east coast, another from the Kapoeas river to the west, a sixth from an unspecified locality. In eight the index was 75 or less; two were from Banjermassin, two from Poeloe Petak, two from the Upper Kapoeas river in Central Borneo, one from Katingan, and one from an unspecified locality. In three with index 76, of which one was from the Tewen river, a source of the Barito river in Central Borneo, and one with index 77, the locality of which was not stated. One from Sango, Sambas Kapoeas had this index, 78, and two from unspecified localities had the length-breadth index 78 and 79.

In Sir Wm. Flower's well-known catalogue† of skulls in the Museum of the Royal College of Surgeons, London, four skulls, highly decorated, from Dutch Borneo are marked "Dyak"; two others, also "Dyak," and one unmarked are from Sarawak and are smoke-stained; a skull from a village on the Pantai river, on the east coast of Dutch Borneo, and another from the north-east coast, said to be a Batta,‡ have cephalic indices respectively 81·5 and 72·6. Two additional skulls have since been acquired by the Museum,§ one from North Borneo, index 69·8, the other, a "Ukeit," index 78·5, from the interior. In this collection the cephalic index was more than 80 in three specimens obtained from the east and west coasts; below 75 in five skulls, of which three were

* *Thesaurus Craniorum*, p. 289 *et seq.*, London, 1867.

† London, 1879.

‡ Barnard Davis catalogues, p. 275, a Batta or Batak skull from the Island of Sumatra, and quotes Junghuhn as locating this tribe in the narrow part of that island.

§ Quoted by H. Ling Roth, vol. 2, p. ccxi, London, 1896.

procured at or near the coast; from 78·3 to 78·7 in three specimens, of which two were from the coast.

MM. De Quatrefages and Hamy, in their classical treatise,* state that nine crania from Borneo, most of which are from the south of the island, are in the Paris Museums, and of these four were dolichocephalic or subdolichocephalic, with the length-breadth index ranging from 72·4 to 74·8; three were brachycephalic and the corresponding index varied from 80·2 to 84·2. In table xlv. they have summarised the characters of eleven male "Dyak" skulls. The mean index of length and breadth was 77·5, of length and height 75·8, of breadth and height 98·5. Swaving is quoted as saying,† the mean cephalic index of ten Dyak skulls from the interior of Dutch Borneo is 74·5.

The Museum in Amsterdam, formed by the Professors Vrolik,‡ contains a skull from Sambas on the west coast of Borneo, which was brachycephalic. Also eight skulls marked "Dyak," two of which were decorated with tin foil; of these one, apparently from Banjermassin, is said to be brachycephalic, also one from Kahayan to be dolichocephalic. Three marked "born at Banjermassin" and three without definite locality are also said to be dolichocephalic, but in none of the specimens is the cephalic index stated.

The crania comprised in the London, Amsterdam and Paris Museums, along with those in the University of Edinburgh Anatomical Museum now described, show that the coasts of Borneo are inhabited by people, as a rule, brachycephalic or approximating thereto, a character which indicates that they are either true Malays, or have Malay affinities and descent. On the other hand, the Kalamantan tribes who occupy the interior of the island, details of whose cranial characters are supplied in this memoir, are dolichocephalic in form and proportions. The cross-breeding which doubtless to some extent takes place between the people of these two different types would account for those skulls which possess the intermediate mesaticephalic characters.

BOTANS OF FORMOSA. Table III. Plates IV., V.

About twenty years ago my friend the late Dr John Anderson, F.R.S., presented to me four skulls from the Island of Formosa. They had been collected on a field of skirmish between the Botans and Japanese, by an American naval officer attached to the Japanese military expedition to that island in 1874–5. The heads had been decapitated by the Japanese soldiers, and the skulls were prepared for the American officer, in whose custody they remained until he presented them to Dr Stuart Eldridge, by whom they were given to Dr Anderson. In 1877 Dr Eldridge read "Notes on the Crania of the Botans of Formosa" to the Asiatic Society of Japan, which were printed in pamphlet form, a copy of which I received along with the skulls from Dr Anderson.

* *Crania Ethnica*, Paris, 1882.
† Quoted by I. H. F. Kohlbrügge in *L'Anthropologie*, t. ix. p. 2, 1898.
‡ *Catalogue of the Vrolik Museum*, by J. L. Dusseau, Amsterdam, 1865.

In this pamphlet Dr ELDRIDGE states that the Botans or Motans are one of the aboriginal tribes of southern Formosa. He describes them as a race of rather fine physical development, of medium height, courageous, frank and impressible like most savages, straight-haired, complexion various, but always of a brown tint, never black. They cultivated the soil, possessed domesticated animals, were fond of the chase, lived under a patriarchal system, and had a rude form of religion, the cult of which was in the hands of priestesses. He noted some of the more prominent characters of the skulls, and gave a number of measurements in inches. Photographs on a small scale of three of the specimens were reproduced in his paper.

As specimens of the skulls of the aborigines of Formosa are seldom met with in Museums, and as Dr ELDRIDGE's Notes seem to have received no attention from anthropologists, I have thought that a more complete description of these skulls, in accordance with modern methods, might prove of interest.

The skulls were those of men in the prime of life. The lower jaw was present in Nos. 1 and 2. No. 1 was in good order; No. 2 had lost part of the frontal, sphenoid and much of the left side of the face; Nos. 3 and 4 were injured and bore the marks of sword-cuts, and the facial bones were absent. In length, breadth and height, and in the horizontal, longitudinal and vertical transverse circumference, the skulls so closely approximated to each other in absolute dimensions and general form that they presented a strong racial or even family resemblance. The skull measurements and indices are given in Table III.

Norma verticalis.—The outline of the cranium, though elongated, was in two specimens a broader ovoid and the cephalic index ranged from 74·6 to 77·3. Nos. 3 and 4 were dolichocephalic and Nos. 1 and 2 were respectively 77·1 and 77·3, *i.e.* in the lower term of the mesaticephalic group. The sagittal region was not ridged, the transverse arc was in some rounded from side to side, the parietal eminences were fairly marked, and the skulls were a little wider in the squamous than in the parietal regions. The slope downwards and backwards in the parieto-occipital region was moderate, there was no artificial flattening, and the occipital squama projected only a little behind the inion. Two skulls were phænozygous, one was cryptozygous.

Norma lateralis.—The frontal eminences were moderate and the forehead was somewhat receding; the glabella and supraorbital ridges were not specially projecting, though most pronounced in No. 3; in all the specimens they could be differentiated from the outer upper border of the orbits. The nasion was not depressed, the bridge of the nose was not flattened, but moderately projecting. The parietal longitudinal arc was the longest and the occipital arc the shortest in Nos. 1 and 2, but the parietal was the shortest and the occipital much the longest in No. 4. The crania rested behind on the cerebellar occipital fossæ in Nos. 1, 2 and 3.

Norma facialis.—The maxillo-nasal spine was moderate in Nos. 1, 2 and 3. The sides of the anterior nares, though sharp in the upper part, were less so lower down, and the incisor border of the nasal floor was smoothed down into the incisive region of the

Table III.

Botans of Formosa and Tibetans.

	Botans.				*Tibetans.*	
Collection mark,	1	2	3	4	C.	D.
Age,	Ad.	Ad.	Ad.	Ad.	Advd.	Ad. Metopic.
Sex,	M.	M.	M.	M.	M.	M.
Cubic capacity,	1380	...	...	...	1570	1230
Glabello-occipital length,	179	176	181	178	186	178
Basi-bregmatic height,	133	133	139	136	140	100
Vertical Index,	*74·3*	*75·6*	*76·8*	*76·4*	*75·3*	*56·1*
Minimum frontal diameter,	93	...	87	90	98	96
Stephanic diameter,	107	107	...	98	105	108
Asterionic diameter,	101	98	105	186	103	120
Greatest parieto-squamous breadth,	138s.	136s.	135s.	133s.	135	141
Cephalic Index,	*77·1*	*77·3*	*74·6*	*74·7*	*72·6*	*79·2*
Horizontal circumference,	515	500	...	500	518	518
Frontal longitudinal arc,	123	120	125	117	125	132
Parietal ,, ,,	129	132	240	115	134	130
Occipital ,, ,,	108	110		131	120	111
Total ,, ,,	360	362	365	363	379	373
Vertical transverse arc,	298	297	308	295	305	281
Basal transverse diameter,	125	127	122	122	120	124
Vertical transverse circumference,	423	424	430	417	425	405
Length of foramen magnum,	36	34	33	35	40	31
Basi-nasal length,	102	103	106	102	104	90
Basi-alveolar length,	98	94	98	...	105	104
Gnathic Index,	*96·1*	*91·3*	*92·5*	...	*101*	*115·6*
Total longitudinal circumference,	498	499	504	500	523	494
Interzygomatic breadth,	132	138	135	130	136	130
Intermalar ,,	122	...	128	...	127	117
Nasio-mental length,	111	106	...	...	...	...
Nasio-mental complete facial Index,	*84·*	*76·8*	...	...	...	...
Nasio-alveolar length,	72	63	67	...	74	65
Maxillo-facial Index,	*54·5*	*45·6*	*49·6*	...	*54·3*	*50*
Nasal height,	55	54	53	...	54	52
Nasal width,	27	25	27	...	28	27
Nasal Index,	*49·1*	*46·3*	*50·9*	...	*51·8*	*51·9*
Orbital width,	39	39	37	...	40	36
Orbital height,	36	34	35	...	36	36
Orbital Index,	*92·3*	*87·2*	*94·6*	...	*90*	*100*
Palato-maxillary length,	53	50	53	...	60	53
Palato-maxillary breadth,	61	63	71	...	67	56
Palato-maxillary Index,	*115·*	*126·*	*134·*	...	*111·*	*105·6*
Nasio-malar Index,	*108·4*	...	*108·3*	...	*107·7*	*102·1*
Cranio-facial Index,	*73·7*	*78·4*	*74·5*	*73·*	*73·1*	*73·*
Lower jaw. Symphysial height,	32	23	...	...	...	...
Lower jaw. Coronoid ,,	69	58	...	...	...	...
Lower jaw. Condyloid ,,	75	62	...	...	...	...
Lower jaw. Gonio-symphysial length,	98	91	...	...	...	...
Lower jaw. Inter-gonial width,	100	...	...	...	...	...
Lower jaw. Breadth of ascending ramus,	42	40	...	...	...	...

maxilla. The mean nasal index was mesorhine, 48·7; in Nos. 1 and 2 the anterior nares were wider absolutely and relatively to the height of the nose, but in No. 2 they were narrower and the index was leptorhine, 46·3. In Nos. 1 and 2 the complete face

was short absolutely and relatively to the interzygomatic breadth, and the complete facial index was chamæprosopic. The disproportion between the interzygomatic breadth and the nasio-alveolar length was, however, not so great, and the maxillo-facial index was in No. 1 leptoprosopic and in Nos. 2 and 3 mesoprosopic. The canine and incisive fossæ were moderate in depth. The interorbital breadth ranged from 19 to 24 mm. The relation of the bi-malar to the nasio-malar diameter gave a nasio-malar index 108·3, so that the nasal profile was mesopic, *i.e.* between a platyopic and pro-opic face. The orbital apertures were rounded and the mean orbital index was megaseme, 91·3. The palatal arch was shallow in one specimen, and wide in all in relation to the length; the palato-maxillary index was brachyuranic, and in two even hyperbrachyuranic. The upper jaw was orthognathous and the mean gnathic index was 93·3.

The cranial sutures were distinct in Nos. 1, 2 and 4, but in No. 3 they were almost obliterated. No. 1 had a small Wormian bone in the occipito-mastoid suture. The ali-sphenoid articulated with the parietal, but in No. 3 the junction was reduced to a pointed bar of bone. Infraorbital sutures were present in Nos. 1 and 2. The jugal processes were somewhat tuberculated, but no skull had a 3rd condyl. The inion, occipital curved lines and mastoids had male characters. The lower jaw was more massive in No. 1 than in No. 2; its vertical diameters were longer and the chin was thicker and more projecting, but in both the angle was almost rectangular and the ascending ramus was broad. The teeth were stained with betel, and the molars were flattened through use on the grinding surface of the crown.

The Botan crania in their proportions were associated with the dolichocephalic type of skull, for whilst two had the cephalic index below 75, the other two were in the lower term of the mesaticephalic group. The mean cephalic index was 75·9, the mean vertical index, 75·7, was hypsicephalic. In the mesaticephalic crania the vertical index was less than the cephalic, but in the dolichocephalic the vertical index was greater than the cephalic, in accordance with the rule that in the dolichocephali the height is more than the breadth. The cranio-facial index ranged from 73 to 78·4, and the mean was 74·9, a figure which associated these relations to the dolichocephalic type in Borneo.

The northern end of Formosa and the fertile plain along the western half of the island have long been frequented for purposes of trade, and they have been occupied successively by the Dutch, Chinese and Japanese, but the mountainous districts in the interior, the south end and the east coast have been little visited, for they have been almost inaccessible through their mountainous configuration and the savage character of the people. Since Formosa was ceded by the Chinese to Japan in 1895, attempts have been made by the Japanese administrators to open up the country, to determine the names of the aboriginal tribes and to locate their position. Much useful information has been collected and embodied by Consul J. N. Davidson in an important volume, well illustrated and provided with a map, compiled from the latest Japanese Government surveys.* He arranges the aborigines in eight groups, and the hilly plains of the south

* *The Island of Formosa Past and Present*, London and New York, 1903.

end of the island are occupied by the Paiwan group, of which the Botans or Bootangs are apparently members.* The Paiwans practise tattooing, they wear a disc of wood in the lobule of the ear, and are head hunters, the heads being stored in enclosures of stone near the houses. Consul R. SWINHOE, who travelled in the southern part of the island, named the aborigines who inhabit the mountains Kalees.† He describes the people as brown or yellowish brown, the eyelids drawn down at the inner angle, eyes far apart, nose of moderate size, neither broad nor flattened, heads shaved, hair plaited into short queues. He considered them to resemble the Tagal people of Luçon in the Philippines. Dr SCHETELIG described four skulls from Formosa.‡ Two of these from the north-east coast were from a tribe which he states is named Shekwan by the Chinese, a term which is synonymous with Sek-hoan, the cooked barbarians of the plain, as the semi-civilised tribes are sometimes called § in contra-distinction to the Chhi-hoans, raw barbarians of the mountains, or unsubdued savages. SCHETELIG stated that these people had a yellow complexion, dark heavy hair, dark eyes, well-shaped oval eyelids, broad nostrils, broad faces, broad prominent cheek-bones. The skulls were oval in outline, not flattened on the roof, the mean cephalic index was 72, the mean vertical index 76·1, *i.e.* more than the cephalic; the skulls were therefore dolichocephalic, and, as is the rule in this group, the height exceeded the breadth. These skulls differed therefore materially in the proportions of the cranium from brachycephalic Malays and brachy- or mesaticephalic Chinese. SCHETELIG also gives a brief account of two skulls obtained, it was said, from a hill tribe in the south of Formosa, which had been so much injured that only partial measurements could be taken; the mean cephalic index was 81·5, and the vertical index, in the only one in which it could be accurately computed, was 76·7. He was of opinion that these skulls showed Malayan affinities, more especially to the wild tribes of Luçon. He considered them to resemble a Malayo-Philippine type.

In regard to the question of the presence of a Negrito element amongst the aborigines of Formosa, SWINHOE hinted at the possibility of the wildest of the mountain tribes being of dwarf stature and allied to the Negritos, though he guarded himself by saying that he had not seen them. A. B. MEYER has discussed with much detail and acumen || the distribution of the Negritos in the Philippine Islands and beyond them. He does not concur in the opinion that Negritos formed a part of the aboriginal inhabitants of Formosa, and he has also been led to the conclusion that their presence in Borneo had not yet been proved. Dr G. L. MACKAY, who spent many years as a missionary in Formosa, and lived for weeks at a time in the villages, made careful inquiries among the mountain tribes in the far south, in the centre and in the north of the island, and was

* In Consul DAVIDSON'S map the most southerly members of this group are named Koaluts.

† *Report of British Association*, p. 129, Birmingham meeting, 1866. *Proc. Roy. Geogr. Soc.*, vol. x. p. 122, 1866.

‡ *Trans. Ethnol. Soc. London*, vol. vii. p. 215, 1869. I have computed the indices from the measurements recorded by SCHETELIG in his table i.

§ *From Far Formosa*, by G. L. MACKAY, D.D., p. 93, Edinburgh and London, 1896. *Pioneering in Formosa*, by W. A. PICKERING, C.M.G., p. 65, London, 1898.

|| *The Distribution of the Negritos*, Dresden, 1899.

definitely told that there were no woolly-haired races within the mountains, or anywhere else in the island.* From tradition and physical characters, he is of opinion that the aborigines are of Malayan origin, and are descendants of emigrants from the Malay Peninsula and the islands of the China Sea. He states that in the practice of tattooing, in head hunting, in their dress, ornaments and houses, and in their ancestral worship they are akin to the hill tribes of Borneo. As with the Kalamantan tribes in Borneo, their heads are dolichocephalic or approximating thereto, and not brachycephalic, a character to which due consideration requires to be given when their possible Malayan origin is under discussion.

INDONESIANS.

The islands off the south and south-east of Asia and the adjacent parts of that continent are peopled by four types of men—Mongolian Chinese, Malays, Negritos, and Indonesians. The Mongols, Malays and Negritos are brachycephalic or approximating thereto in cranial form and proportion. The term Indonesian, suggested by J. R. Logan, was employed by M. Hamy in 1877† to express aboriginal people properly belonging to the great islands of the Indian Archipelago, and it has even been extended so as to include the brown-skinned Polynesians of the easternmost islands of the Pacific. As the Polynesians and some of the tribes in the Indian Archipelago have crania of the brachycephalic type, the term Indonesian would therefore be held to embrace races whose skulls are brachycephalic in proportions. Other anthropologists, again, and in this I am disposed to concur, employ the term to designate tribes in whom the head and skull are dolichocephalic in form and proportion, or approximating thereto,‡ with a mesorhine nose, brown skin, varying in the depth of tint, long, straight, black hair, short stature, 5 ft. 2 in. to 5 ft. 4 in. The Kalamantans of Borneo are typical Indonesians. The Battaks of Sumatra are also regarded as Indonesians: MM. De Quatrefages and Hamy refer to the skull of a Battak in a museum in Göttingen with the cephalic index 70·1; to two others in the Batavian Museum with almost the same proportions; the specimen in the Barnard Davis collection had the index 77. Kohlbrügge states that the Tenggerese, a mountain race in Java,§ are Indonesians. His measurements were not on skulls, but on living people, and he gave the mean cephalic index of 130 individuals, 79·7, mesaticephalic, which in the skull would have yielded an index about 77. In Timor, Celebes‖ and other islands of the Archipelago Indonesian

* *From Far Formosa* (*op. cit.*).

† E. T. Hamy, "Les Alfourous de Gilolo d'après de nouveaux renseignements," in *Bull. Soc. de géogr. de Paris*, 6th série, t. xiii. p. 491, 1877; also "Les races Malaïques et Américaines," in *L'Anthropologie*, t. vii., 1896. J. Deniker, *The Races of Men*, London, 1900.

‡ In previous Memoirs (*Trans. Roy. Soc. Edin.*, vol. xxxix. p. 744, 1899, and vol. xl. p. 596, 1903) I have noted the importance of dividing the mesaticephali into two groups, those with index below 77·5 approximate to the dolichocephali, whilst those with index above 77·5 approximate to the brachycephalic type.

§ *L'Anthropologie*, t. ix. p. 1, 1898.

‖ Since this memoir was in type I have, through the courtesy of Drs Paul and Fritz Sarasin, received a copy of the Memoir of Dr Fritz Sarasin, *Versuch einer Anthropologie der Insel Celebes*, Wiesbaden, 1906. An elaborate account

tribes have been studied whose heads are either dolichocephalic or approximating thereto. Professor CLELAND found * the proportion of the length to the breadth of the cranium in a Sulu Islander to be 75.

In a recent important treatise on the people of the Philippine Islands, based on the study of 270 skulls in the Museum at Leiden, G. A. KOEZE has figured and described the cranial characters of various tribes in these islands. † He recognises Negritos, whom he regards as the original inhabitants, Malays from two successive invasions separated by an interval of many years, Chinese, Japanese, and to a lesser extent Europeans. Moreover, he thinks that the dolichocephalic Tagbanua tribe is the remains of a Melanesian stock which had formerly lived in the Philippines. Cross-breeding between these races had taken place, varying in its proportion in the different tribes. He regards the Ilocanos as having the purest Malay blood; the Visayans and Tagals possess a large proportion, but also have Indonesian characters. The Igorrots, he states, are especially Indonesian; he concludes, however, that they are a cross between the Negritos and the Malays of the first invasion, though those who live in the north of Luçon show traces of Mongolian intermixture. The Igorrots in the cranial length and breadth are, from VIRCHOW'S observations, mesocephalic with a great tendency to be dolichocephalic. KOEZE, again, of twelve crania found seven mesocephalic and five definitely brachycephalic, with a mean index 80·5; he sums up, therefore, that the type is mesocephalic with a great tendency to be brachycephalic. He looks upon the Igorrots as corresponding with the "Dyaks," and they are also head hunters. If the Igorrots are to be regarded as a cross between the Negrito and Malay, and at the same time Indonesians, and if a similar origin is to be associated with the Indonesian tribes of Borneo, it is difficult to comprehend how a cross between two brachycephalic races like the Negrito and Malay could produce dolichocephalic tribes such as the Kalamantan Muruts, and Dusuns. It seems, therefore, that the dolichocephalic Indonesians in their origin and descent should not be regarded as the product of cross-breeding, but that they rather are a race independent and definite in their characters. When the cephalic index is brachycephalic or approximates thereto in a so-called Indonesian tribe a cross-breeding with Malay, Negrito or Mongol may be inferred.

We may now pass, by way of the Philippine Islands, northward to the Island of Formosa. Here, as has already been stated, we find, amongst the mountains, tribes with skulls either dolichocephalic or closely approximating thereto, with brown skins, straight black hair, and from their practice of head hunting and other customs resembling the hill tribes of Borneo. It seems appropriate to associate them with the Indonesian race, which constitutes therefore a distinct factor in the population of the

is given of the external physical characters and of the measurements of the head and body of living natives. Owing to the almost impossibility of obtaining human skulls and skeletons in the course of their travels in Celebes, the authors were not able to give an account of the osteology of the people on lines similar to those pursued in their great work on the Weddas and other people in Ceylon.

* *Journal of Anat. and Phys.*, vol. xi. p. 663, 1877.

† *Crania Ethnica Philippinica*, Haarlem, 1901–1904.

great islands from Sumatra to Formosa, although modified in some localities by intermixture with Negrito, Malay, Chinese, and even Arab blood.

Turning now to the southern part of the Asiatic Continent we find in the Malay Peninsula three definite types of men.* The Semangs, a typical Negrito race, brachycephalic, with black skins, short woolly hair, broad flat noses, eyes open, not oblique, low stature, 1491 mm.; the Malays, some civilised, others savage, brachycephalic, with dark yellow or copper-coloured skins, long straight smooth hair, flattish nose, wide nostrils, high cheek-bones, eyes moderate in size, rarely oblique, stature a little higher than in the Semangs; the Sakais, or Senoi as Professor RUDOLF MARTIN prefers to name them,† are dolichocephalic, skin from dark brown to yellowish brown, hair long, black, wavy, nose not so broad and flat, high cheek-bones, eyes small, horizontal, stature slightly more than in the Semangs. In their physical characters the Sakais correspond in head form with the Indonesians, whilst the colour of the skin and the character of the hair are not unlike in the two, but in stature they are a pigmy race.

Two Selung skulls brought from the Mergui Islands on the west coast of the Malay Peninsula by Dr JOHN ANDERSON, which I measured at his request,‡ had the cephalic index 76·3 and 76·6 respectively; in the male the cranial height was more than the breadth, but in the female a little less, probably a sexual difference; in one the nose was mesorhine, in the other platyrhine. Although the index was mesaticephalic, it was in the lower term of that group, and pointed to the affinity of the people with a long-headed race. The skin was reddish brown, darker and not with the olive tint of the Malays, the hair long, coarse, black, with sometimes a tendency to curl, eyes black and slightly oblique. The Selungs show in some respects Indonesian characters, with possibly a Malay intermixture. A proportion of the people of the Nicobar Islands would seem to be dolichocephalic. The savage tribes, named by DENIKER§ the Mois, who occupy in Cambodia the country between the Mekong river and the coast of Annam, are dolichocephalic, about 5 ft. 2 in. in stature, skin yellowish brown, hair more or less wavy, eyes straight, and they have apparently Indonesian characters.

The hill districts to the north of Burma are occupied by tribes known as Lushais, Chins, and Nagas,‖ the crania of which are, as a rule, dolichocephalic or approximating thereto, and I have described crania from Upper Burma itself possessing definite dolichocephalic form and proportions. From Colonel WADDELL's measurements of the heads of the people in the Brahmaputra valley¶ it is obvious that in some of these

* See the writings of NELSON ANNANDALE, RUDOLF MARTIN, and Messrs SKEAT and BLAGDEN already referred to in note on p. 797. Also my memoirs on Indian Craniology, Part ii., chapter on the Sakai, in *Trans. Roy. Soc. Edin.*, 1901; W. L. H. DUCKWORTH, *Studies from the Anthropological Laboratory*, Cambridge, 1904.

† The term Sakai is used by many travellers as a generic term to include all the pigmy wild tribes in the Malay Peninsula. In the subdivision of these into groups, whilst one is named Semang, it is advisable, as MARTIN suggests, that another term than Sakai should be applied to another of the subdivisions, hence his name Senoi.

‡ My description of the skulls, now in the Anatomical Museum of the University of Edinburgh, is included in Dr ANDERSON's memoir on the Selungs of the Mergui Archipelago, London, 1890.

§ *The Races of Men*, London, 1900.

‖ I have described their crania in Part i. of my contributions to Indian Craniology, *Trans. Roy. Soc. Edin.*, 1899.

¶ *Journ. Asiatic Soc. Bengal*, vol. lxix. pt. iii., Calcutta, 1901.

tribes the skulls would be dolichocephalic, and I have elsewhere described the skull of a Kham warrior from Eastern Tibet which was distinctly dolichocephalic.

In the Island of Ceylon the Veddahs are a pronounced dolichocephalic people. In the form of the cranium, and in their long, black, wavy hair, the Veddahs have affinities with the Sakais (Senoi) of the Malay Peninsula. In India itself the Tamils and Pariahs of southern India, the Gonds, Oráons, Paháriás, Múndas, Kols and Bhúmij of the Central Provinces constitute, under the collective name of the Dravidians, a definite portion of the population, and possess marked dolichocephalic skulls.*

It is obvious, therefore, that both in the groups of islands and in the southern part of the adjacent continent, in addition to such well-marked brachycephalic types as the Negritos, Malays and Mongolians, people with skulls dolichocephalic in form and proportions are widely diffused. The dolichocephalic people, though corresponding in the character of the cephalic index, vary amongst themselves in some other respects. The nose, though not leptorhine, is often platyrhine as in the Dravidians, but mesorhine in other tribes; the face is sometimes low, chamæprosopic, at others relatively longer and narrower, leptoprosopic; the orbits in some are low, microseme, in others more rounded, megaseme; the upper jaw is either ortho- or mesognathous, seldom prognathous. The palato-maxillary arch is usually brachyuranic. The skin varies in colour from dark brown, or almost black, in the Dravidians to a lighter or even yellowish brown in the islanders; the hair is black, long, straight, though occasionally wavy; the stature is generally from 5 ft. to 5 ft. 4 or 5 in., but in the Sakais (Senoi) it is below 5 feet or pigmy. Subject to these modifications, a general physical type prevails in these scattered dolichocephalic people, one which in many respects corresponds with that so often referred to as Indonesian. It is not unlikely that they may in the main have a common descent, though, owing to their wide diffusion in southern Asia and the adjacent islands, which has brought them into close contact with such potent races as the Mongols, Malays, Negritos, Melanesians, and even Polynesians, they have become modified, and the character of the modification has been influenced by that of the race with which an intermixture of blood has been effected.

Even if we were to give as wide an interpretation to the term Indonesian as is above indicated, there would be no difficulty in differentiating them from the dolichocephalic, black skinned, black frizzly haired, platyrhine, prognathic Melanesians, or from the dolichocephalic, black skinned, black straight haired, platyrhine, prognathic aborigines of the Australian Continent.

In writing this chapter on the Indonesians I have confined myself to the consideration of the physical characters which bear on the affinities of the several tribes, and I have made no reference to the important subject of linguistic relations, a department of anthropology outside the range of my studies. I would only remark that although the Malay tongue and its dialects are spoken throughout the Archipelago and as far north as Formosa, both by Malays and Indonesians, this, in itself, does not

* See for measurements and other details my memoirs on Indian Craniology already referred to.

prove that community of language implies common descent and race. Examples are not unknown elsewhere of a race having lost its original tongue and speaking a language acquired from another race with which it has been brought into intimate contact, through conquest, immigration, or otherwise.

Tibetans. Table III. Plate V.

In Part iii. of my series of Memoirs on the Craniology of the People of the Empire of India I described and figured the skulls of two natives of Tibet, which had been presented in 1905 by Major C. N. C. Wimberley, I.M.S. One of these, from Lhasa, was an example of the brachycephalic type; the other, a warrior from the Kham province in Eastern Tibet, on the other hand, was dolichocephalic in form and proportions. The skulls were representative of the two distinct types of head which exist in the people of Tibet. These skulls are marked A and B in the list of Tibetan crania in the University Museum. In connection with these specimens, I discussed the physical characters and affinities of the Tibetans.

I have the pleasure of acknowledging the receipt, in October 1906, of two skulls and a skull bowl or cap collected at Gyantse, Tibet. They were presented by Lieutenant F. M. Bailey, the British Agent at the town of Gyantse, and they had been prepared for him by Captain Rt. Steen, I.M.S., the Agency Surgeon. The skull bowl was said to be a part of a Khamba skull, but no special information is given regarding the other specimens.

I have carefully examined the two skulls, which I shall designate C and D. They were both males and had reached adult life, though, from the condition of the sutures and teeth, C was obviously much older than D. The lower jaws were absent.

Skull C. *Norma verticalis.*—The cranial outline was an elongated ovoid, dolichocephalic, cephalic index 72·6; there was no sagittal ridge, and though the slope from the sagittal suture to the parietal eminences was well marked, the vertex could scarcely be called roof-shaped; the side walls were almost vertical, the parieto-occipital slope was moderate, and the occipital squama projected behind the inion. The skull was phænozygous.

Norma lateralis.—The forehead slightly receded; the glabella and supraorbital ridges were moderate, and the latter were not fused with the outer upper border of the orbit, above which, as in the Kham skull, the frontal was flattened as far as the temporal ridge.* The nasion was not depressed. The bridge of the nose had a low mesial keel and the profile outline showed a shallow concavity. The nasal bones at the mid suture were 24 mm. long. The parietal longitudinal arc was the longest, the occipital arc the shortest. The cranium rested behind on the cerebellar fossæ.

* Professor Cunningham, in the study of the evolution of the region of the eyebrow, has pointed out the morphological importance of distinguishing the supra-orbital ridge and the upper border of the orbit, in their bearing on the significance of the great ridges which are found in such a skull as that from the Neanderthal.

Norma facialis.—The floor of the nose was smoothed down into the incisive region; the maxillo-nasal spine was low, the incisive and canine fossæ were deep. The anterior nares were wide, but, owing to the nasal height, the nasal index was not platyrhine but mesorhine, 51·8. The nasio-malar index was 107·7 and the facial profile was mesopic. The face was wide, 136 mm., but, as the superior maxillæ were relatively long, 74 mm., the maxillo-facial index, 54·3, was leptoprosopic. The upper jaw was mesognathic with an index 101. The interorbital width was 26 mm. The orbital aperture was rounded and the index, 90, was megaseme. The palate was deeply arched, being 17 mm. in depth opposite the 2nd molar; the palato-maxillary index, 111, was mesuranic. The teeth were much worn, but were not stained. The cranio-facial index, 73·1, was low, in harmony with the dolichocephalic type.

The sutures of the cranial vault, the squamous excepted, were almost obliterated; a small epipteric was in the right pterion. The temporal curved lines were well marked, but the occipital curved lines, inion and mastoids were moderate. The jugal processes were tuberculated. The cephalic index, 72·6, was dolichocephalic, the vertical index, 75·3, was hypsicephalic, and the basi-bregmatic height exceeded the greatest breadth.

Skull D.—This skull showed structural peculiarities which had accentuated individual characters and had doubtless modified the racial features. Most remarkable was the great development of Wormian bones in the lambdoid and squamous sutures. In the lambdoid these bones were usually four-sided and the transverse diameter was the shorter; they had long denticulations intercalated between corresponding processes of the parietal and occipital bones, and as the ossicles were directed obliquely they caused the occipital squama to project backwards behind the parietal, so as to form a shelf-like projection at the back of the skull and to modify the length of the cranium.* The sutural bones in the squamous regions were much smaller, and were arranged so as to push the squamous temporals laterally, beyond the plane of the parietals, and to add to the breadth of the cranium in these regions. The alisphenoid had a narrow articulation with the parietal. A small Wormian was in the anterior sagittal suture and the frontal was metopic. Another character was a fissure which cut across the basis-cranii, 7 mm. in front of the foramen magnum, and was continued laterally into the jugular foramina. The basion sloped upwards so as to affect the measurements made from it, the plane of the foramen magnum was directed upwards and forwards, and the occipital condyls were flattened, but there was no 3rd condyl. It was difficult to say definitely if the basi-cranial fissure was a congenital defect in ossification, or was due to fracture produced during life, though the former is probably the correct explanation.

Norma verticalis.—The cranial outline was broadly ovoid and not quite symmetrical, owing to the arrangement of the Wormian bones. The vault was not ridged and the parietal eminences were feeble. The cranium was cryptozygous.

* This peculiar feature has been from time to time noticed by previous writers. Lucæ has figured two specimens in *Zur Architectur des Menschenschädels*, plates ii., xii., Frankfurt, 1857. In the Edinburgh University Museum are two skulls dating from the time of the Monroes, one of which I have figured in fig. 26. They show the character in an extreme form, and several added by myself exhibit it in a minor degree.

Norma lateralis.—The forehead was almost vertical, the glabella and supraorbital ridges were feeble, the nasion was not depressed, the nasal bones in the mesial line were 23 mm. long; the bridge was not keeled, the nose was flattened at its root and projected so slightly in front of the outer borders of the orbits that the nasio-malar index was only 102, and the nasal profile was markedly platyopic. The interorbital width was 23 mm. The frontal longitudinal arc was the longest, the occipital was the shortest. The cranium rested behind on the cerebellar fossæ, which were unusually bulging.

Norma facialis.—The maxillo-nasal spine was moderate and the floor of the nose was smoothed off into the incisive region. The canine fossæ were deep. The anterior nares were wide and the nasal index was in the upper mesorhine group, 51·9. The upper jaw was somewhat prognathic, but the displacement of the basion interfered with the normal measurements from that region, and the gnathic index, computed by FLOWER'S method, was 115·6. The face was wide, the cheek bones were prominent, and, as the vertical diameter of the maxillæ was small, the maxillo-facial index was chamæprosopic. The interorbital width was 23 mm. and the orbital apertures were round and megaseme, index 100. The palate was shallow and elongated, the index, 105·6, was almost dolichuranic. The teeth were lost except a right molar, the crown of which was worn. The cranio-facial index was 73.

The cephalic index, 79·2, placed the skull in the higher term of the mesaticephalic group, and the vertical index, 56·1, was remarkably low, but, owing to the osteological peculiarities of the cranium already described, the measurements of length, breadth and height were affected, and their respective indices cannot be relied on as giving definite racial characters; though, as the sutural bones had influenced both the length and breadth of the cranium, it is possible that the lambdoidal and squamosal ossicles may partially counterbalance each other in their effect on these two dimensions (Pl. V. fig. 25).

There can be no doubt that the skull C is dolichocephalic in form and proportions. In length, breadth, height, horizontal and vertical transverse circumference, nasio-malar, cranio-facial and maxillo-facial indices, it is closely allied to the measurements of the Kham warrior described in my previous memoir. It differs from it in the orbital and palato-maxillary indices being somewhat less, and in the nasal and gnathic indices being larger, so that the relative width of the anterior nares and the projection of the upper jaw are greater. The two skulls corresponded, however, with each other in so many important characters that there seems little doubt that the skull C from Gyantse was of the same race as the one from the Kham province.

Owing to the variations in the cranial bones, already described, in D, it is probable that the race type in it is modified and concealed by the special characters of the skull. It would, however, seem as if it approximated to the brachycephalic type, and was, perhaps, a cross between the broad-headed Mongolian and the long-headed race which obviously constitutes an important element in the population of Tibet.

The bowl or cap which accompanied the two skulls had evidently been carefully

removed from the base of its skull, for the sawn edge was horizontal and had been polished. I compared it with some specimens of Tibetan praying drums in the Anatomical Museum of the University, formed by the apposition of the vaults of two skull bowls, and I have little doubt that the cut section had been covered with a layer of dried skin, and had formed one of the two segments of a praying drum. The Tibetans evidently regard the bowl of the skull as an object to be utilised in religious ceremonial and as having a symbolical or mystic signification. Colonel WADDELL, in his admirable work on Tibet,* gives a figure "Revelation Gospels" in which a skull bowl is held in the left hand and a trumpet formed of a human thigh bone in the right, and another figure of a hermit of the order of St Mila who holds a skull bowl also in the left hand. The conversion of the femur into a trumpet is another example of the utilisation of a part of the human skeleton in the ceremonial observances of the people of Tibet, and the Museum possesses several specimens of this kind.

In this skull bowl the section had been made a little above the glabella through the supra-nuchal part of the occiput, and below the highest part of the squamous suture. The length was 176 mm. and the greatest breadth 134 mm., which gave an index 76·1. If the glabella had been present, the index would have been a little less, so that the skull had probably been dolichocephalic. In the bowls of the two praying drums in the Museum the section had been made somewhat higher in the skull, and the relations of length and breadth could not so well be determined.

SAGITTAL SECTIONS.

In this memoir, as in its predecessors, I have reproduced tracings of sagittal sections of some of the skulls which have been described, in order to show the contour of the skull immediately on one side of the mesial plane. Lines, radiating from the basion to definite points on the surface of the skull, as well as other lines which pass between other anatomical points, have been drawn. As I have explained the direction of the lines and the position of their terminal points in my *Challenger Report*, and in Part iii. of "The Craniology of the People of the Empire of India," I may refer to these memoirs for a detailed description of the significance of the lines. The measurements and the points between which the lines were drawn are given in Table IV.

In comparing the measurements of the three skulls with each other, it should be kept in view that they differ in the proportions of length and breadth. The Murut is dolichocephalic, the Botan from Formosa is mesaticephalic, the Bajau is brachycephalic. Whilst those radial measurements which express the height of the cranium as the basi-lambdal, -perpendicular and -bregmatic, show comparatively little difference in the three crania, the radii which run more in the direction of cranial length, as the basi-inial, -glabellar, -nasial, are much shorter in the Bajau than in the other crania.

* *Lhasa and its Mysteries*, London, 1905.

Table IV.

Sagittal Sections.

	Murut A. C.In. 73·9.	Bajau M. C.In. 82·9.	Botan 1, Formosa. C.In. 77·1.
Basi-inial radius.	83 mm.	75 mm.	81 mm.
,, occipital ,,	96	98	106
,, lambdal ,,	112	113	110
,, perpendicular ,,	136	139	134
,, bregmatic ,,	135	137	133
,, glabellar ,,	107	100	111
,, nasial ,,	101	96	102
,, alveolar ,,	94	93	98
Nasio-tentorial plane,	176	158	175
Tentorio-bregmatic line,	88	89	86
,, perpendicular ,,	90	93	88
,, lambdal ,,	56	58	49
,, occipital ,,	7	28	36
Nasio-bregmatic chord,	108	107	110
Perpendicular therefrom to outer table of frontal,	27	26	26
The same to inner table,	20	20	20
Fronto-occipital diameter of cerebral cavity,	163	151	161
From perpendicular radius to frontal pole of cavity,	90	82	78
From perpendicular radius to occipital pole of cavity,	73	72	83

This difference in the antero-posterior diameter of the brachycephalic Bajau is also very marked in the length of the nasio-tentorial plane and of the fronto-occipital diameter of the cerebral cavity above that plane. The cavity in front of the perpendicular radius expresses generally the position and extent backwards of the frontal lobe of the cerebrum, its antero-posterior diameter is longest in the dolichocephalic Murut and shortest in the Botan; whilst the part of the cavity behind that radius, in which the parietal and occipital lobes are lodged, is shortest in the Bajau, and much the longest in the Botan. The series of measurements above the nasio-tentorial plane, more or less vertical in direction, which express the height of the cerebral cavity, though not differing much from each other in the bregmatic and perpendicular regions, show a marked difference in the tentorio-lambdal and -occipital regions, for whilst in the former the Bajau is the longest and the Botan much the shortest, in the tentorio-occipital the Botan is the longest and the Murut is remarkably small. The arc of the frontal bone and the space in the cerebral cavity bounded by the nasio-bregmatic chord, to which attention has been especially called by Professor Cunningham, is almost equal in the three crania. The length of the cerebral cavity between the frontal and occipital poles and the height as expressed by the collective tentorio-bregmatic, -perpendicular, -lambdal, and -occipital diameters in the three crania are as follows: Murut, L. 163 mm., H. 241 mm. = 404; Bajau, L. 151, H. 268 = 419; Botan, L. 161, H. 259 = 420. In the collective dimensions of length and height the Bajau and Botan crania are

almost equal to each other, and to the Múnda skull measured in Part iii. Table VI. of my series of Indian Memoirs. The corresponding dimensions in the Murut skull are distinctly smaller. The sections do not permit the breadth of the cranium to be given.

I have computed in the three crania the length of the three factors which make up the longitudinal circumference of the skull so that they may be compared with the corresponding dimensions of the skulls measured in my previous memoirs.

	Murut A.	Bajau M.	Botan 1.
Base line,	139	133	138
Longitudinal arc,	369	361	360
Longitudinal circumference,	508	494	498
Base line to longitudinal arc,	2·6	2·7	2·6
Base line to longitudinal circumference,	3·6	3·7	3·6

By the base line, a term employed by Professor CLELAND, is meant the length of the foramen magnum along with the basi-nasal diameter. It will be seen that the proportion of base line to the longitudinal arc or to the longitudinal circumference is almost the same in the three crania. They closely correspond with the proportions which I showed to exist in the Tamils, Pariahs, Veddahs, and Kham skulls described in Part iii. of my Memoirs on Indian Craniology.

EXPLANATION OF PLATES I.–V.

The process blocks are reproduced from photographs of the skulls prepared by Messrs John Henderson and William Gill of the Anatomical Museum.

Plate I.

Fig. 1.—Murut, face view. Table I., A.
„ 2.—The Same, vertex view.
„ 3.—The Same, profile view.

Fig. 4.—Dusun, face view. Table I., H.
„ 5.—The Same, vertex view.
„ 6.—The Same, profile view.

Plate II.

Fig. 7.—Land Dyak, face view. Table II., O.
„ 8.—The Same, vertex view.
„ 9.—The Same, profile view.

Fig. 10.—Sea Dyak, face view. Table II., P.
„ 11.—The Same, vertex view.
„ 12.—The Same, profile view.

Plate III.

Fig. 13.—Bajau, face view. Table II., M.
„ 14.—The Same, vertex view.
„ 15.—The Same, profile view.

Fig. 16.—Kweejow, face view. Table I., L.
„ 17.—The Same, vertex view.
„ 18.—The Same, profile view.

Plate IV.

Fig. 19.—Botan of Formosa, face view. Table III., 1.
„ 20.—The Same, vertex view.
„ 21.—The Same, profile view.

Fig. 22.—Malay from Perak, face view. Table II., P.
„ 23.—The Same, vertex view.
„ 24.—The Same, profile view.

Plate V.

Fig. 25.—Tibetan, profile view. Table III., D.
„ 26.—Skull in Anatomical Museum. This and the Tibetan skull are figured to show the variation in the form of the occiput, due to the remarkable development of the Wormian bones.

Fig. 27.—Sagittal section through skull of Murut A
„ 28.— „ „ „ Bajau M.
„ 29.— „ „ „ Botan 1.

In the sections the lettering is as follows :—

b. al. basi-alveolar radius.
b. n. basi-nasal. „
b. g. basi-glabellar „
b. br. basi-bregmatic „
b. p. basi-perpendicular „
b. oc. basi-occipital radius.
b. in. basi-inial „
f. m. plane of foramen magnum.
n. t. nasio-tentorial plane.
n. br. nasio-bregmatic chord.

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SIR WILLIAM TURNER on "Craniology of Natives of Borneo, Malays, Formosa."—PLATE I.

FIG. 1.—Murut.

FIG. 4.—Dusun.

FIG. 2.—Murut.

FIG. 5.—Dusun.

FIG. 3.—Murut.

FIG. 6.—Dusun.

SIR WILLIAM TURNER on "Craniology of Natives of Borneo, Malays, Formosa."—PLATE II.

FIG. 7.—Land Dyak.

FIG. 10.—Sea Dyak.

FIG. 8.—Land Dyak.

FIG. 11.—Sea Dyak.

FIG. 9.—Land Dyak.

FIG. 12.—Sea Dyak.

SIR WILLIAM TURNER on "Craniology of Natives of Borneo, Malays, Formosa."—PLATE III.

FIG. 13.—Bajau.

FIG. 16.—Kweejow.

FIG. 14.—Bajau.

FIG. 17.—Kweejow.

FIG. 15.—Bajau.

FIG. 18.—Kweejow.

SIR WILLIAM TURNER on "Craniology of Natives of Borneo, Malays, Formosa."—PLATE IV.

FIG. 19.—Formosa.

FIG. 22.—Malay.

FIG. 20.—Formosa.

FIG. 23.—Malay.

FIG. 21.—Formosa.

FIG. 24.—Malay.

SIR WILLIAM TURNER on "Craniology of Natives of Borneo, Malays, Formosa."—PLATE V.

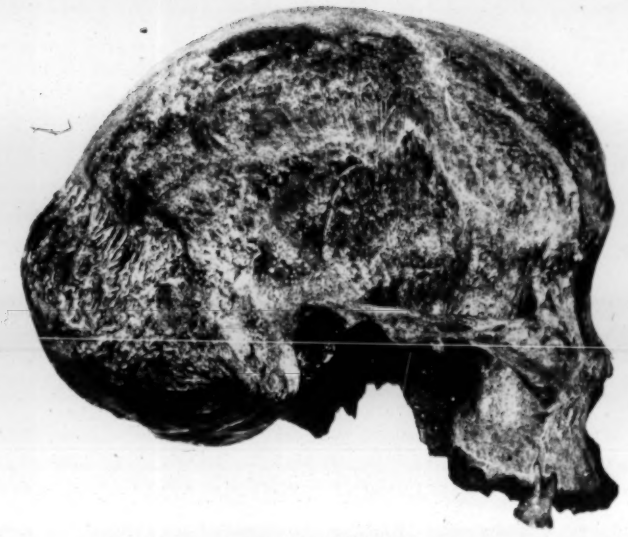

FIG. 25.—Tibetan.

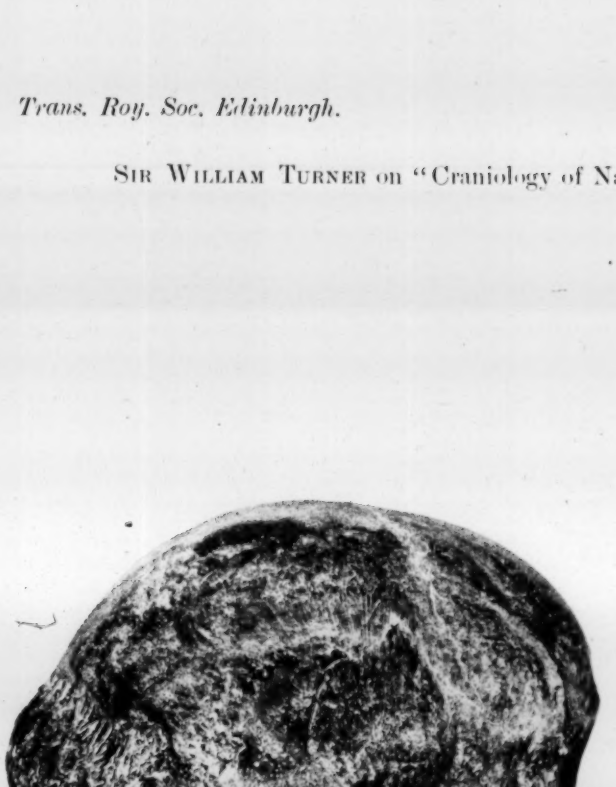

FIG. 27.—Murut.

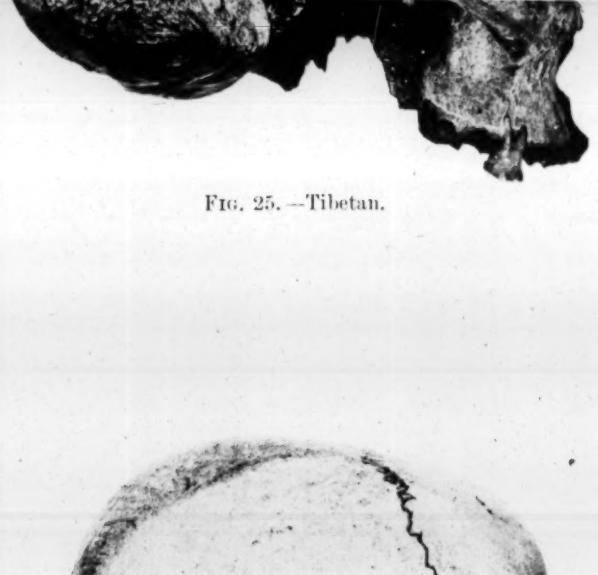

FIG. 28.—Bajau.

FIG. 26.

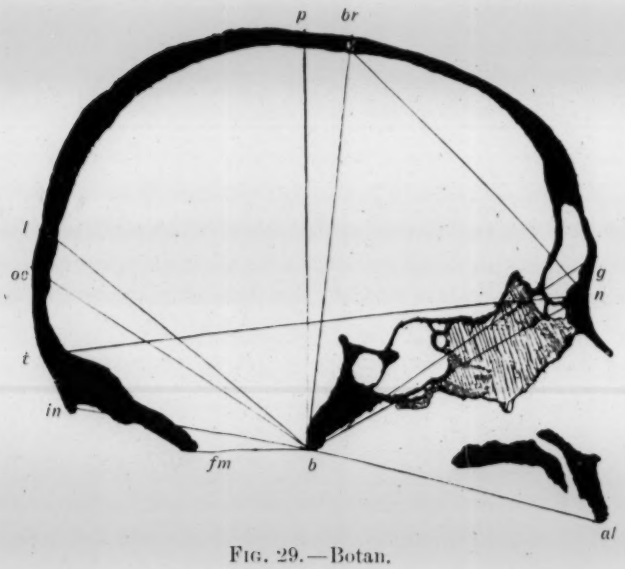

FIG. 29.—Botan.

XXIX.—Turbellaria of the Scottish National Antarctic Expedition.

By **Dr J. F. Gemmill** and **Dr R. T. Leiper.*** *Communicated by* Sir JOHN MURRAY, K.C.B.

(With a Plate.)

(Read March 5, 1906. Issued separately August 7, 1907.)

There were seven Turbellaria in the material handed to us by Mr W. S. BRUCE, all obtained in April 1903 from Scotia Bay, South Orkney Islands (9–10 fms., Station 325, lat. 60° 44′ S., long. 44° 51′ W.). Their occurrence is interesting, as, although STUDER (*Ueber Seethiere aus dem Antarktischen Meere*, 1876) mentions, without adequately describing it, a *Eurylepta* from Kerguelen Island, there are no definite records, so far as we have been able to ascertain, of Turbellarian species from nearer the Antarctic than the coasts of South America.

POLYCLADA.

Tribus *Cotylea*. Fam. *Euryleptidæ*. Genus *Aceros* (1). *Aceros stylostomoides*, n. sp.
(Plate figs. 1 and 2.)

Specific Diagnosis.—An *Aceros* with mouth and male opening extremely closely approximated; with dorsal pore connecting the hinder part of the main gut with the dorsal surface; with about fifteen eyes on either side in the brain groups, and eight to nine in the marginal groups.

The two examples of this species are much curled. They measure 3–4 mm. in length and ·9 mm. in greatest thickness, and they are of a warm brown tint, mottled on the dorsal surface by a coarse, darkly pigmented network, the strands of which arise from a longitudinal band on either side of the middle line.

As the specimens differ in the relative degree of contraction of certain parts (notably the pharynx), they will be distinguished hereafter, when necessary, as specimen (*a*) and specimen (*b*).

Body Wall.—The musculature is strong ventrally, especially in the region of the sucker, but over the dorsum it is weak, being channelled by the coloured network mentioned above. This appears to be formed by spaces within and immediately beneath the muscular layer, containing numerous minute round particles of brownish black pigment. The sucker lies a little behind the middle of the body. In specimen (*a*) its centre is near the junction of the third and fourth body fifths, and in specimen (*b*) slightly further forward. It is of large size and slightly elevated.

Digestive System.—The mouth (external opening of pharyngeal sac) is situated at the commencement of the second body fifth. In specimen (*a*) the pharynx measures less than a fifth of the body length, its own length being about a fifth greater than its

* This paper was prepared in part during Dr Leiper's tenure of a Carnegie Research Scholarship.

breadth, while the pharyngeal sac and the pharynx are contained within the second body fifth. In specimen (*b*) the pharynx is longer and more cylindrical. In both specimens the lumen of the pharynx is dilated just in front of its oblique opening into the gut.

The main gut is spacious and extends to near the posterior end of the body, giving off five lateral roots on either side and a median anterior root. All the roots branch freely without apparently anastomosing. The main gut opens to the external surface by a ciliated pore in the mid-dorsal line near the commencement of the last body fifth in specimen (*a*), and rather further forward in specimen (*b*).

Brain.—The brain is large and lies close in front of the wall of the pharyngeal sac. With the anterior gut root it occupies the entire depth of the interior of the body in the middle line.

Eyes.—Immediately beneath the basement membrane and overlying the brain are two groups of eyespots each containing about fifteen ocelli. These groups are separated from one another by the anterior gut root. Deeply sunk in the parenchyma, on the outer anterior surface of the brain on either side, is a single ocellus similar to that described by LANG in *Aceros inconspicuus* (1); there are also eight to nine eyespots scattered along the anterior body margin on either side of the middle line. These may be described as tentacular eyes, though actual tentacles are absent from this as from the other species of *Aceros*.

Genital Organs.—The male aperture lies immediately behind the mouth in specimen (*a*), while in specimen (*b*), owing apparently to differences in muscular contraction, it might almost be described as having a common opening with the mouth.

The male organs consist of penis, "granule gland," seminal vesicle, vasa deferentia, and testes.

The penis is large, of an elongated, pyriform shape, almost equal in length to the retracted pharynx in specimen (*a*), but slightly shorter in specimen (*b*). The lumen of the penis is dilated posteriorly, and is lined by a single layer of greatly elongated cells. Its relatively thin muscular wall forms a uniform sheet round the dilated part of the lumen and tapers off gradually towards the apex. The lumen of the penis is connected posteriorly by an extremely fine passage with the large "granule gland" (prostatic vesicle). This passage receives from behind the minute canal from the seminal vesicle. The "granule gland" vesicle is lined by a single layer of cubical, non-ciliated epithelium covered by a thin muscular wall. The seminal vesicle has a strong muscular wall and is filled in both specimens with spermatozoa. It lies behind the "granule gland" and below the gut, and ends in a pair of vasa deferentia which by rapid and repeated branching come into connection with the small and very numerous lobules of the testis. These lobules are scattered throughout the lateral parts of the body in the septa between the gut branches, ventral to the ovarian tubes.

The female apparatus consists of aperture, shell-gland portion, duct of uterus, uterus, oviducts, and ovarian tubes.

The aperture lies just in front of the sucker; the shell-gland portion is short and dilated and has highly glandular walls. The tissue surrounding it, as well as that around the lower end of the uterine duct, is crammed with granules. The uterine duct, which is dilated, but empty in both specimens, is lined by cells possessing remarkably long cilia, and passes backwards below the gut, to end in the two uteri into which the oviducts open. The ovaries are found throughout the lateral parts of the body, dorsal to the testes. Many of the ovarian tubes contain yolk-like material, which seems to be derived from the transformation of cellular elements within their walls. This arrangement seems to replace the special uterine glands described as occurring in *Aceros inconspicuus* and certain other *Euryleptidæ*.

Systematic.

The specimens described above may be included in the Euryleptid genus *Aceros*, LANG, as amended by PLEHN (2). The original description of the genus is as follows (1): —Körper glatt; Mund unmittelbar hinter dem Gehirn; Pharynx cylindrisch; Hauptdarm mit circa fünf Paar Darm-ast-wurtzeln; Darm-äste nicht anastomosirend; männliche Oeffnung sehr nahe hinter dem Mund; männlicher Begattungs-apparat unter dem Pharyngeal-tasche; weiblicher mit seiner Oeffnung dicht hinter derselben; ein Paar Uterus-drusen; sehr wenige Augen (jederseits drei) im Gehirn-hof; sehr wenige Augen in je einer seitlichen Gruppe am vorderen Körper-rande an der Stelle wo bei den verwandten Gattungen die Tentakeln stehen die bei dieser Gattung fehlen.

Two species of *Aceros* have been described, viz., *A. inconspicuus*, LANG (1), the species for the reception of which the genus was founded, and *A. nationalis*, PLEHN (2).

A. inconspicuus, from the Gulf of Naples, is a small member of the genus measuring 3 mm. long by 1·3 mm. broad. The dorsal surface is mottled, owing to the presence of finely granular pigment under the basement membrane. Over the brain there are two groups of three eyes, the outermost eye on each side being deeply sunk and lying on the outer anterior surface of the brain. There are four marginal eyes on either side, evidently in the position of the absent marginal tentacles. The mouth is in front of the end of the first body fourth. The male opening is close behind the mouth; the female opening is a little in front of, and the sucker a little behind, the middle of the body.

A. nationalis, from the neighbourhood of Cape St Vincent, is larger, measuring 5 mm. by 2·5 mm., and has a large cylindrical pharnyx, which in the retracted condition measures one-fourth of the body length. The mouth is at the beginning of the second body sixth, the male opening at the end of the second body fifth, and the female opening almost exactly in the middle of the body. Behind this lies the sucker, which is large and muscular. Over the brain area there are two groups of eyespots each containing twelve to fifteen ocelli. The marginal ocelli are about thirty on either side.

For the reception of *A. nationalis* within the genus *Aceros*, PLEHN amends LANG's

description of the genus by leaving out reference to the very small number of eyes characteristic of *A. inconspicuus* as apparently not of generic importance, and, by substituting "under or close behind the pharyngeal sac" for "under the pharyngeal sac" to indicate the position of the male apparatus. The first of these alterations is required by *A. stylostomoides*, but in regard to the position of the male apparatus this species conforms to the generic type as instituted by LANG.

In the Euryleptid genus *Stylostomum* (3), mouth and male aperture open together by a common antrum, and there is no median anterior gut root. LANG remarks that, except for these two points, *Stylostomum* is almost exactly the counterpart of *Aceros*. It is noteworthy therefore to find that in *A. stylostomoides* the male opening and the mouth are so closely approximated that in certain states of contraction they may almost be said to open together.

The presence of a dorsal pore in *A. stylostomoides* is extremely interesting. The pore canal passes downwards and forwards from the surface to the hinder part of the main gut in the median line, and is clothed by epithelium agreeing in character with the body epithelium except that its cells are provided with longer cilia. The basement membrane is continued down the wall of the canal, and there are sphincter fibres at the junction with the gut.

Dorsal pores are described by LANG as occurring in *Cycloporus*, *Yungia*, and probably also in *Oligocladus* (4). In *Cycloporus* they are very numerous and occur near the body margin. Here the extremities of the ultimate gut branches become enlarged to form vesicles which open on the dorsal surface, each by a tiny pore.

In *Yungia* the pores occur on the dorsal surface at the places at which the anastomosing gut branches meet. Here short diverticula from the branches end in small vesicles opening by the pores.

In *Oligocladus* the hindmost gut root on either side sends a diverticulum backwards towards the dorsal surface in the middle line. These meet with one another and with a mesial process from the main gut in a cell mass close under the dorsal body epithelium. LANG was not able to find a pervious canal opening on the surface through the cell mass in question, but he considers that in all probability this was due to contraction of the tissues.

The same author suggests that such pores may be considered as being homologous with an anus, and that the numerous marginal pores in *Cycloporus* may be looked upon as representing a primitive condition recalling the marginal excretory pores of Cœlenterates.

In *Yungia* the pores, though fewer, are still numerous, and scattered over the lateral parts of the dorsum; while in *Oligocladus* there is only one pore, but it is connected with the two last gut roots as well as with the main gut. *A. stylostomoides* would complete the series, inasmuch as it has a single opening which is comparatively large, and is connected only with the main gut.

We are of opinion, however, that these pores, occurring as they do in a few

scattered species of Turbellaria, are to be looked upon as new formations without phylogenetic importance.

It may be well to summarise here the points in which this new species of *Aceros* differs from those previously described.

A. stylostomoides differs from *A. inconspicuus*, LANG (recorded from the Gulf of Naples):—

1. By the number of eyes (*a*) in the brain groups (about fifteen in the former and three in the latter on either side), and (*b*) in the tentacular groups (eight to nine in the former and four in the latter on either side);

2. By the presence in the former of a dorsal pore leading into the main gut;

3. By the absence from the former of special uterine glands.

A. inconspicuus differs from *A. nationalis*, PLEHN (recorded from the neighbourhood of Cape St Vincent):—

1. By the much greater approximation in the former of the mouth and the male aperture. In the latter these openings are separated by fully a sixth of the body length;

2. By the number of eyes in the tentacular groups (eight to nine in the former and thirty in the latter on either side);

3. By the presence in the former of a dorsal pore and the absence of separate uterine glands.

POLYCLADA.

Tribus *Cotylea*. Genus (nov.) *Nuchenceros*, referred provisionally to Fam. *Euryleptidæ*, LANG. Type, *Nuchenceros orcadensis*, n. sp. (Plate figs. 3–6).

Two examples of this extremely interesting polyclad were obtained, the one (specimen *a*) having its male structures in maturity, the other (specimen *b*) being quite immature. They measure respectively 4·5 and 4 mm. in length, are oval in shape, and of a brownish colour which is lighter underneath. The surface is destitute of papillæ. Their most striking characteristic is the presence of a pair of slender nuchal tentacles studded with eyes and containing no visceral branches. The tentacles in question measure an eighth of the body length, and are situated at a sixth of the body length from the anterior margin.

Eyes.—The eyes are in three groups on either side: (1) anterior marginal, three to four in number, large, and embedded in the parenchyma; (2) tentacular, about twenty-four in number on either side, clustered thickly, especially on the outer and anterior sides of the tentacles; (3) cerebral, a somewhat diffuse group comprising (*a*) eyes right over the brain, (*b*) eyes lateral to the brain, and (*c*) eyes behind the brain, and occurring as far back as the junction of the first and second body thirds. The cerebral subgroups are not definitely separated from one another, and the total number of eyes they contain is about thirty on either side.

Brain.—The brain lies in front of the mouth, at the junction of the first and second body fifths.

Sucker.—The sucker, which is large and slightly elevated, lies a little in front of the middle of the body. It rests on a pad of muscular tissue which is continued into the walls of the posterior part of the pharyngeal sac. Here the tissue in question is permeated by fine mucous canals which open into the sac.

The older specimen (specimen *a*) is much injured dorsally, and has its pharynx retracted to an extreme degree. Partly owing to the injury and partly to the extremely hard nature of the tissues below the pharyngeal sac, a satisfactory series of sections of this specimen was not obtained. This circumstance is all the more to be regretted seeing that the smaller specimen, though it furnished a good series of sections, was quite immature as regards the genital organs.

Digestive System.—The mouth lies in front of the brain and opposite the tentacles, at one-sixth of the body length from the anterior body margin. The pharyngeal sac is long and narrow, with a backward diverticulum above the position of the sucker. In specimen (*b*) the pharynx, which is long, tubular, and tapering towards the apex, lies fully extended within the pharyngeal sac. (Plate fig. 4.) In specimen (*a*) the pharynx is completely retracted within the posterior part of its sac, the mouth leading first into a slightly dilated part from which the sac is continued backwards as a narrow canal to the posterior dilatation in which the pharynx lies. The cavity of the pharynx opens into the gut a little behind the junction of the first and second thirds of body length.

The main gut is spacious, extending forward for a considerable distance in front of the internal opening of the pharynx. The lateral gut roots are five in number on either side, and some of their branches anastomose near the margin. The anterior gut root extends forward over the middle part of the brain and divides without anastomosing with any of the branches of the first lateral gut roots.

Genital Organs in Specimen (*a*).—The male opening lies close behind the mouth and leads into a penis sheath cavity of considerable size. (It must be stated here that, owing to the injured condition of the specimen, the succeeding part of this description of the male organs may not be quite complete or accurate, and it is therefore liable to correction should further specimens be obtained.) At the bottom of the penis sheath cavity is a small conical elevation, above which is a muscular backward diverticulum of the penis sheath cavity. (Plate fig. 5.) The elevation is perforated by a fine passage which appears to be continuous with the central canal of an oval organ lying close behind. The walls of this organ are so hard and dense as to show practically no histological structure. Into the posterior end of its central cavity opens a short canal formed by the union of the two vasa deferentia. These last are full of spermatozoa and irregularly dilated, each exhibiting a very large swelling just before its first main branch is given off. The lobules of the testis are numerous, large, and scattered throughout the lateral parts of the body.

The conical elevation mentioned above may represent an apical portion of the penis, and the oval organ a combined bulbar portion and granule gland. A vesicula seminalis appears to be awanting, its place being taken by the much-dilated vasa deferentia. The dorsal diverticulum of the sheath cavity may have something to do with the mechanics of protrusion of the bulbar part of the penis.

The immature specimen has no male external opening, but in a mass of parenchym cells below the anterior part of the pharyngeal sac there are two small cavities connected with one another. (Plate fig. 3.) These probably represent the penis sheath cavity and the granule gland (bulbar portion of penis). From the dorsal side of the first a minute cavity arises which probably gives rise to the apical portion of the penis. The vasa deferentia unite behind the granule gland without opening into it, and they are traceable for a considerable distance as narrow, undilated canals. It is remarkable that at this stage there is no communication between the various cavities mentioned above and the external surface.

Female Organs.—The female opening in specimen (*a*) lies just in front of the sucker and near the junction of the first and second thirds of body length. It leads by a narrow canal into the widened shell-gland portion. The duct of the uterus is traceable for a short distance as a solid mass of cells, but its cavity is not yet developed. Uteri and oviducts cannot yet be made out, and the ovarian tissue is in an extremely embryonic condition. In the immature specimen only the cavity of what is probably the shell-gland portion is recognisable (Plate fig. 3), and like the male cavities it is cut off from the external surface.

Systematic.

Until other species of this genus are found and described, it would be premature to delimit the characters in the above description that are of generic from those of specific importance. We therefore confine ourselves to designating *N. orcadensis* as type of the genus, referring to the above description for details, and summarising the outstanding characters as follows :—

Slender nuchal tentacles containing eyes but no gut branches ; large sucker situated a little in front of the middle of the ventral surface ; mouth in front of brain ; pharynx long, tubular ; pharyngeal sac with a backward extension above the sucker ; gut with unpaired anterior and five pairs of lateral roots ; genital apparatus entirely beneath the pharyngeal sac.

In general structure *Nuchenceros* resembles the Euryleptid genus *Oligocladus*, Lang (5), having like it the mouth in front of the brain, the pharynx long and tubular, and the genital openings below the pharyngeal sac which extends backwards above the sucker. But in *Oligocladus* the tentacles are of the marginal type containing gut branches, while *Nuchenceros* has nuchal tentacles such as are characteristic of the Acotylean *Planoceridæ*.

Again, according to our description, the male organs of *Nuchenceros* resemble those

found in *Planocera insignis* in the features wherein these organs differ from the Euryleptid type, *i.e.* absence of vesicula seminalis and of a separate granule gland (6).

Nuchenceros appears therefore to exhibit certain characters intermediate between the two great polyclad tribes the *Acotylea* and the *Cotylea*. Probably in the end a new Cotylean family will have to be created for its reception; but meanwhile, until the characters of the genital organs are more definitely determined, we think it best simply to call attention to its close general resemblance to *Oligocladus*, a member of the family *Euryleptidæ*, notwithstanding the fact that none of the *Euryleptidæ*, and indeed none of the *Cotylea* hitherto described, possess true nuchal tentacles.

Reference is made by LANG (7) to imperfect descriptions by KELAART (8) and COLLINGWOOD (9) of an Acotylean species from Ceylon, called by the former *Planaria meleagrina* and by the latter *Stylochoplana meleagrina*, which possesses both marginal and nuchal tentacles. As LANG considers that the nuchal tentacles of polyclads are the more primitive, and the marginal ones are newer formations, he is not surprised that cases should occur in which both kinds are present, but he would naturally expect such cases to be Acotylean. In this connection it is worthy of special note that *Nuchenceros* has a tentacular group of eyes in addition to the marginal and cerebral groups.

In any case it is evident that the usually accepted definition (10) of the tribus *Cotylea* must be widened by the exclusion or modification of the two following phrases, "Ohne Tentakeln oder mit Randtentakeln," "Ausser den Gehirnhofaugen kommen auf dem Nacken keine anderen Augengruppen (Tentakelaugen der Acotyleen) vor," in order that this tribus may still include *Nuchenceros*, with its special tentacles and the groups of eyes associated with them.

TRICLADIDA.

Three specimens identified as belonging to the species *Gunda Ohlini*, BERGENDAL, which has been recorded from the coast of Patagonia (11).

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(5) ,, ,, ,, p. 580, and *Atlas Taf.*, 30.
(6) ,, ,, ,, pp. 236–7.
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EXPLANATION OF FIGURES.

ag. Anterior gut root or its branches.
br. Brain.
br.e. Eyes belonging to the brain area group.
ep. Surface epithelium.
fa. Female aperture.
fo. Female organs (undeveloped) in fig. 3.
g. Main gut.
*g.*1. First lateral gut root.
*g.*2. Second „ „
*g.*3. Third „ „
gr.g. Granule gland (prostatic vesicle).
m. Mouth.
ma. Male aperture.
mc. Mucous canals in the muscular tissue behind pharyngeal sac.
mu. Muscular layer of body wall.
mu.s. Sphincter muscle of pore canal in fig 3.
p. Dorsal pore.
pe. Penis.
ph. Pharynx.
p.ho. Internal opening of pharynx.
ph.s. Pharyngeal sac.
ps. Penis sheath.
s. Sucker.
sg. Shell gland.
t. Tentacle.
vs. Vesicula seminalis.
ut.d. Efferent canal of uterus.
ut. Commencement of uterus.

DESCRIPTION OF PLATE.—(For lettering see above.)

Fig. 1. Sagittal section of *Aceros stylostomoides* (specimen *a*).

Fig. 2. Dorsal pore of *A. stylostomoides* (specimen *b*). The canal is oblique and of considerable length, its lumen being fairly uniform but slightly contracted near its inner and outer ends. The cells lining it are richly ciliated.

Fig. 3. Sagittal section through genital region of immature *Nuchenceros orcadensis*, highly magnified. Description on p. 7. There is no connection at this stage between the various cavities and the external surface.

Fig. 4. Sagittal section of *Nuchenceros orcadensis* (specimen *b*).

Fig. 5. Sagittal section of *N. orcadensis* (specimen *a*).

Fig. 6. Longitudinal section of *N. orcadensis* (specimen *a*), passing through the tentacle on one side. The absence of visceral branches in the substance of the tentacle will be noted.

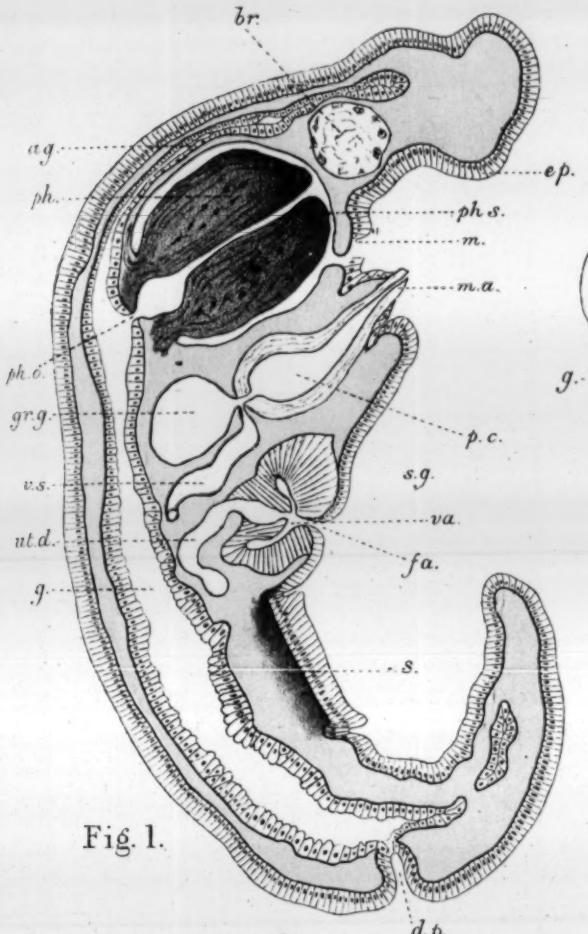

Fig. 1.

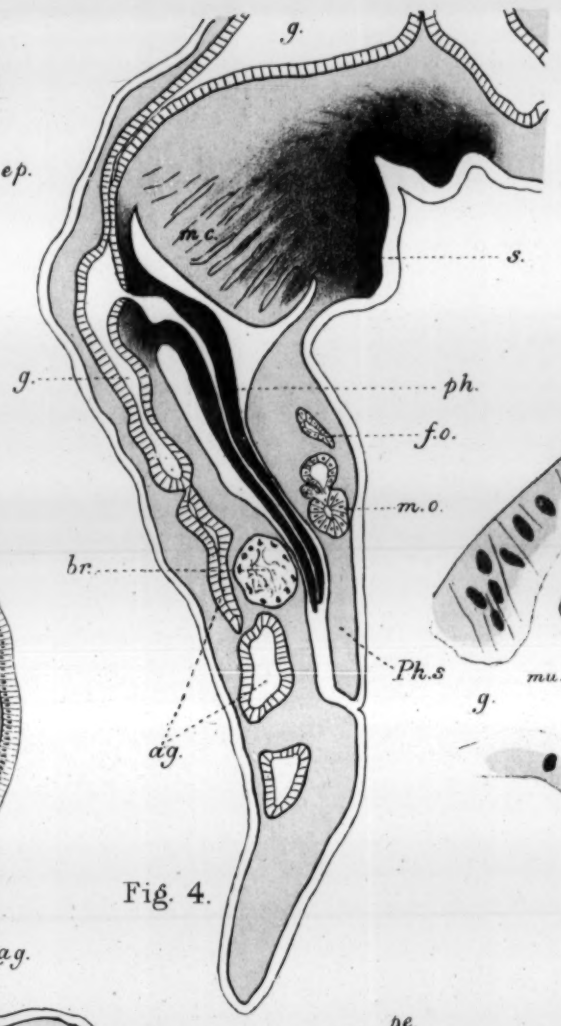

Fig. 4.

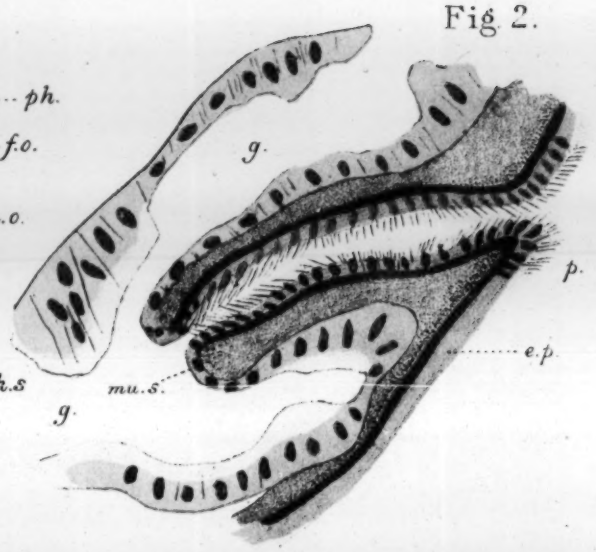

Fig. 2.

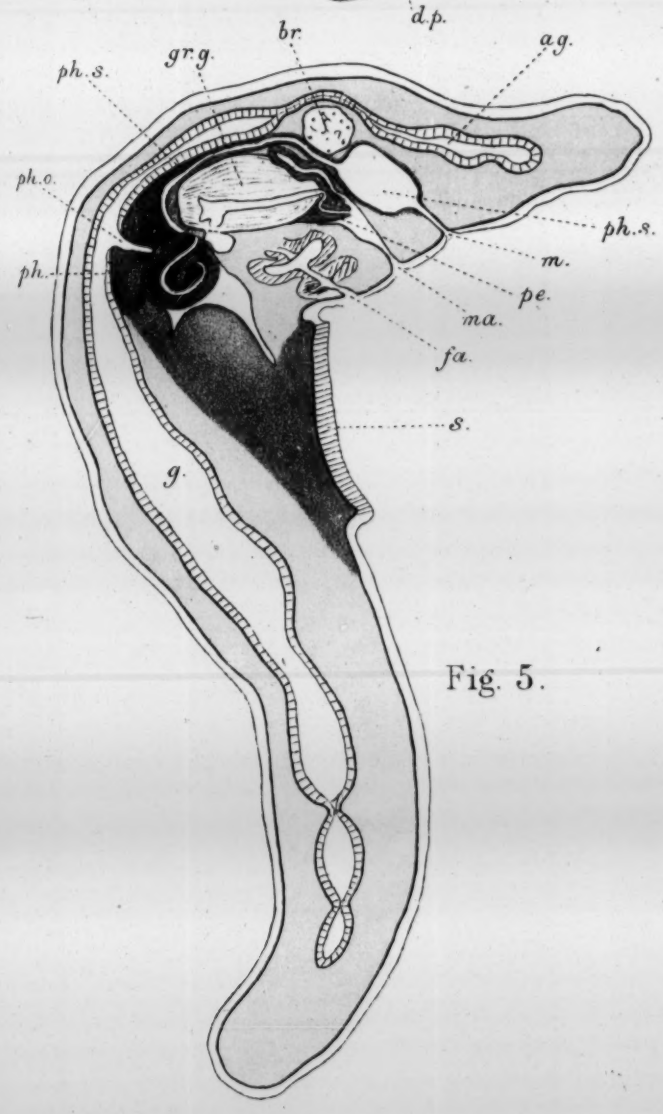

Fig. 5.

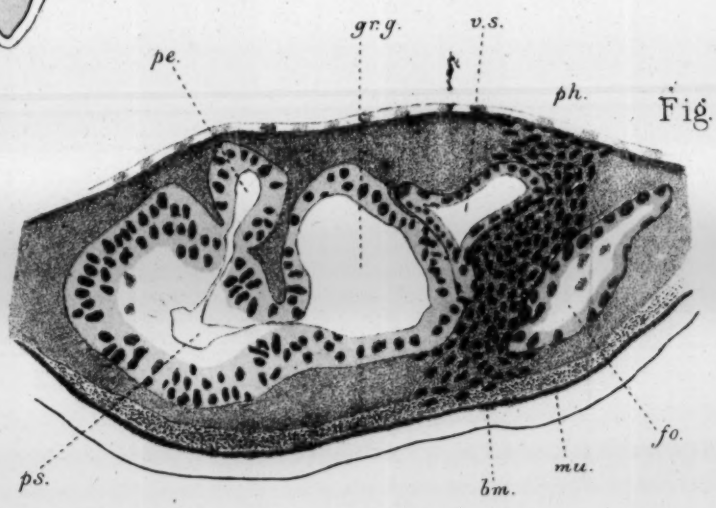

Fig. 3.

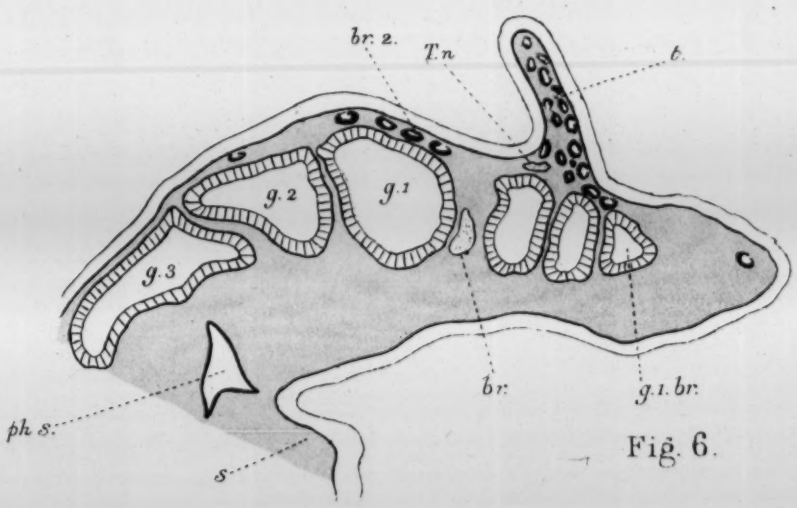

Fig. 6.

XXX.—On a New Siphonogorgid Genus Cactogorgia*; with Descriptions of Three New Species.

By James J. Simpson, M.A., B.Sc., Carnegie Research Scholar, Natural History Department, University of Aberdeen. *Communicated by* Professor J. Arthur Thomson, M.A., F.R.S.E. (With a Plate.)

(Read November 19, 1906. Issued separately September 5, 1907.)

Among the numerous littoral Alcyonarians collected by the Royal Indian Marine survey ship *Investigator* in the Indian Ocean there are five small Siphonogorgids of exceptional interest and apparently new to science. As some time must elapse before the publication of the complete memoir on the Indian Ocean collection, it seems advisable to make a separate report on these new forms. In so doing, I must acknowledge my indebtedness to Professor A. Alcock, F.R.S., and Professor J. Arthur Thomson, M.A., F.R.S.E., University of Aberdeen, for the opportunity of studying these interesting forms, and to the latter also for much kind advice and encouragement.

Systematic Position.

The new type belongs to the order Alcyonacea, family Nephthyidæ, and the exceptionally dense spiculation of the canal walls indicates its position in the sub-family Siphonogorginæ (Wright and Studer, *Challenger Reports, Zoology*, vol. xxxi.). In certain respects it shows affinities with the *Chironephthya-Siphonogorgia* type, but the following differences may be noted:—

(1) The colony is much more densely spiculose, firm and rigid;

(2) There is a marked distinction into trunk and polyp-bearing portion;

(3) There is no definite branching, but the polyps are borne mainly on the margin of flattened lobes.

Generic Diagnosis.

The colony is upright, with a basal attachment, and resembles a Cactus in its mode of growth; it consists of (1) a sterile trunk, very rigid and densely spiculose, in which several small cylindrical canals are imbedded; and (2) an upper polyp-bearing portion, which in some cases bears expanded lobes. There is generally a flattening of the polyp-bearing part and lobes, and the polyps are borne in several rows, for the most part along the margin. The anthocodiæ are completely retractile within more or less prominent verrucæ composed of large spicules arranged longitudinally; they are comparatively large and bear a dense armature with a "crown and points" arrangement.

* The generic name *Cactogorgia* is suggested by the general resemblance to a Cactus-type of growth.

The tentacles are not retractile, but are simply infolded and overlap the oral region; they are covered on the aboral surface with numerous scale-like sclerites. The spicules vary in type in the different parts; those of the stem and trunk are thick spindles covered with multituberculate warts; those of the anthocodiæ ("crown and points") are straight or curved spiny spindles or clubs; those on the aboral surface of the tentacles are small, flat, and scale-like.

The specimens differ so much from one another that they seem to require the definition of three new species, for which the following names are proposed:—*Cactogorgia celosioides*, n. sp., from its resemblance to *Celosia*; *C. expansa*, n. sp., from its flattened appearance; *C. alciformis*, n. sp., from its antler-like mode of growth.

Specific Diagnoses.

C. celosioides, n. sp.—The stem and polyparium are much flattened, of a light brown colour, stiff and rigid, with a translucent sheen. The cœnenchyma is densely spiculose, with the spicules arranged longitudinally. The polyps are borne in several rows along the margin; the verrucæ are cylindrical and distinct; the anthocodiæ have a dense armature—a "crown" consisting of 7–10 rows of curved spindles and "points," each composed of a single pair of spindles with occasionally one or two smaller ones between; the tentacles bear numerous small scales arranged "en chevron" on the aboral surface. The spicules of (A) the stem and polyparium are transparent spindles with numerous multituberculate warts; (B) those of the anthocodiæ are spiny spindles, straight or curved, and clubs; (C) those on the tentacles are scales. The following are typical measurements of length and breadth in millimetres:—(A) $2{\cdot}2 \times 0{\cdot}55$; $0{\cdot}75 \times 0{\cdot}3$. (B) $0{\cdot}95 \times 0{\cdot}18$; $0{\cdot}85 \times 0{\cdot}1$. (C) $0{\cdot}07 \times 0{\cdot}035$.

C. expansa, n. sp.—The stem is cylindrical, the polyparium flattened; both are stiff and rigid, with a densely spiculose cœnenchyma, very opaque in appearance. The spicules of the cœnenchyma lie in all directions. The polyps arise from the margin of the colony; the verrucæ are not very conspicuous; the anthocodiæ are densely covered with spicules having a "crown and points" arrangement; the crown consists of about 8 rows; the points consist of 6–8 pairs "en chevron," and increasing in size towards the apex. There are numerous small scale-like spicules on the aboral surface of the tentacles. The spicules are opaque and yellowish; those of (A) the stem and polyparium are multituberculate spindles; those of (B) the anthocodiæ are spiny spindles or clubs; those on (C) the tentacles are pale yellow transparent scales. The following are average measurements of spicules length by breadth in millimetres:—(A) $1{\cdot}5 \times 0{\cdot}3$; $1{\cdot}1 \times 0{\cdot}2$. (B) $0{\cdot}8 \times 0{\cdot}1$. (C) $0{\cdot}04 \times 0{\cdot}015$.

C. alciformis, n. sp.—The stem and polyparium are sinuous, much contorted, antler-like, stiff, rigid, and translucent; the cœnenchyma is densely spiculose, and the spicules are disposed in all directions and interlock. The polyps occur on the margins of small lobes; the verrucæ are well developed and cylindrical; the anthocodiæ are large, and

bear a distinct "crown and points" armature visible to the naked eye; "the crown" consists of 10–14 rows of curved spindles; the "points" are composed of 10–15 spicules slightly "en chevron." The spicules are transparent: (A) those of the stem and polyparium are warty spindles; (B) those of the anthocodiæ are spiny spindles and clubs; (C) those on the tentacles are scale-like sclerites. The following are average measurements length by breadth in millimetres:—(A) $1{\cdot}6 \times 0{\cdot}45$; $0{\cdot}6 \times 0{\cdot}15$. (B) $1{\cdot}2 \times 0{\cdot}1$; $0{\cdot}5 \times 0{\cdot}05$. (C) $0{\cdot}12 \times 0{\cdot}02$; $0{\cdot}04 \times 0{\cdot}02$.

Distribution.

All the specimens are from the Indian Ocean, and seem to be of a semi-littoral nature. *C. celosioides*, n. sp., is recorded from the Andamans (depth uncertain); *C. expansa*, n. sp., was dredged off Cape Comorin in 38 fathoms; while *C. alciformis*, n. sp., occurs both at the Andamans and off the Arakan coast; at the latter place it was found in 13 fathoms.

More Detailed Description.

Owing to the denseness of the spiculation and the consequent damage in decalcification, it was impossible to investigate the histology of these specimens; but the following more detailed descriptions may give some basis and justification for ranking them under a new and distinct genus.

Cactogorgia celosioides, n. g. et sp. (figs. 1, 2, 3*a*, 3*b*, 3*c*).

This species is represented by two small specimens of a light brown colour. They present a characteristic appearance which suggests in many respects the structure of the coxcomb (*Celosia*). Both specimens are attached by a slightly expanded disc to pieces of detached rock. The first has a cylindrical stalk 16 millims. in length and 6 millims. in diameter, but expanded at the disc of attachment to 10 millims.; this is surmounted by an upper polyp-bearing portion flattened in one plane and almost semicircular in outline; it is 20 millims. in length and 19 millims. in breadth just above its insertion on the stalk. The second specimen (fig. 2) has a more irregular contour. The barren stem is also flattened in the plane of expansion of the polyparium; it is 17 millims. in length and 11 millims. in breadth, and supports a polyp-bearing portion 19 millims in height and 16 millims. in breadth. From the base of the stem an offshoot or lobe 8 millims. in height and 9 millims. in breadth is separated by a constriction, and this part also bears polyps almost over the entire hemispherical head.

Both the colonies are stiff and rigid, owing to the dense network of large warty spindles, which are quite visible to the naked eye. These are arranged for the most part longitudinally, and their transparency gives the whole a translucent sheen.

Traces of the canals passing to the polyps can be observed on the otherwise flat sterile sides.

The stem is traversed by several (about 12) narrow cœnenchymal longitudinal canals, which are almost equally distributed from the centre to the circumference; these are supported by very thick walls densely packed with large tuberculate spindles. The canals pass upwards and branch, so that each polyp is connected with the main portion by means of solenia.

The polyps are situated on the edge of the flattened disc (like the flowers in *Celosia*) in 4–6 indefinite rows. Each is supported by a hollow cylindrical calycine portion 1·5 millims. in diameter, strengthened by large longitudinally arranged spindles, the points of which project and form a protection for the completely retractile anthocodia. An aberrant polyp arises near the middle of the sterile disc; a slight ridge marks the position of the canal from which it takes its origin, and it is possible that this might have been the origin of a lobe similar to that at the base of the colony.

The anthocodiæ (fig. 1) are about 1 millim. apart, and when exserted, but with the tentacles infolded, have a height of about 2·75 millims. and a diameter of 1·5 millims. The "crown and points" arrangement described by Professor HICKSON for *Chironephthya* is a very prominent feature. The "crown" consists of 7–10 rows of curved spicules placed circumferentially and loosely interlocking. Surmounting this there are eight triangular points, each consisting essentially of two large, slightly curved spindles enclosing an acute angle and touching on their convex sides. Between these, however, there are occasionally one or two smaller spindles disposed more horizontally. When at rest, the tentacles are simply infolded and overlap one another; when expanded, they have a length of about 1 millim.; their aboral surface is covered with small scale-like spicules disposed "en chevron," but enclosing a very obtuse angle.

Ova 0·3 millim. in diameter are very abundant on the mesenterial filaments, but, in spite of their large size, they showed, even when stained, no trace of segmentation.

The spicules are of three kinds, which correspond to the various positions in the colony. The following are some of the measurements of length by breadth in millimetres:—

A. Stem and expanded sterile portion—transparent spindles densely covered with compound warts (fig. 3*a*)—

(1) Spindles markedly tapering—2·2 × 0·55; 2 × 0·5; 1·8 × 0·4.

(2) Half-spindles or clubs—1·05 × 0·25; 0·8 × 0·3; 0·75 × 0·3.

B. Anthocodiæ—pale yellow spiny spindles and scales.

(1) "Crown"—warty curved spindles (fig. 3*b*)—0·95 × 0·18; 0·85 × 0·14.

(2) "Points"—warty spindles straight, curved, or club-shaped (fig. 3*b*)—0·95 × 0·1; 0·9 × 0·15; 0·85 × 0·1.

(3) Tentacles—scale-like, with irregular edges; many are constricted near the middle (fig. 3*c*) 0·08 × 0·02; 0·07 × 0·035; 0·06 × 0·02.

Locality.—Andamans.

Cactogorgia expansa, n. sp. (figs. 7, 8, 9*a*, 9*b*, 9*c*).

Of this species there is but a single specimen, of a pale chocolate colour; it is 35 millims. in height and 30 millims. in maximum breadth. It has a somewhat cylindrical stem surmounted by two fan-shaped polyp-bearing lobes, which give it a reniform appearance (fig. 8). The sterile stem is 19 millims. in height and 7 millims. in diameter; the lobes are respectively (1) 16 millims. in breadth, 11 millims. in height, with a width of 11 millims. at the constriction; and (2) 18 millims. in breadth, 14 millims. in height, with a width of 13 millims. at the constriction. One of the lobes, owing to a downward growth, has become slightly convoluted. This species resembles *C. celosioides*, n. sp., in general character, but the general tone is more opaque.

The polyps, as in the first species, occur mainly on the periphery, but this feature is not so marked; several arise on the flattened portion from points in close proximity to the circumference. The stalk is quite destitute of polyps.

Several canals penetrate the stem; these have very thin walls, but maintain their cylindrical form by reason of the rigidity of the cœnenchyma. They branch in the polyp-bearing part, and separate canals may be traced to the individual polyps.

The cœnenchyma is densely spiculose. The spicules on the surface are opaque and appear white; they are arranged in a very irregular manner, so that they present a peculiar and characteristic appearance quite distinct from that in *C. celosioides*, n. sp.

The verrucæ are not very conspicuous; they are supported by spicules arranged for the most part longitudinally, but often quite irregularly. The anthocodiæ (fig. 7) are about 1·5 millims. in length and 1 millim. in breadth when partially extruded. They bear a distinct "crown and points" arrangement. The "crown" consists of about 8 rows of curved spicules interlocking more closely in the upper portion of the stomodœal region. Surmounting this are eight points composed of 6–8 pairs of slightly curved or club-shaped spindles arranged "en chevron"; these increase in size towards the base of the tentacles. On the aboral surface of the tentacles there are numerous small scale-like spicules arranged longitudinally.

The spicules are predominantly spindles; the following are some of the measurements of their length and breadth in millimetres:—

A. Stalk:—opaque yellowish multituberculated spindles—straight and curved—
1·5 × 0·3; 1·4 × 0·25; 1·1 × 0·2 (fig. 9*a*).

B. Anthocodiæ—

(1) "Crown and points"—slightly opaque or translucent tuberculated spindles and clubs—0·8 × 0·1; 0·75 × 0·08; 0·7 × 0·075 (fig. 9*b*).

(2) Tentacles—pale yellow, transparent scales—0·08 × 0·02; 0·06 × 0·02; 0·04 × 0·015 (fig. 9*c*).

Locality.—Off Cape Comorin, 38 fathoms.

Cactogorgia alciformis, n. sp. (figs. 4, 5, 6*a*, 6*b*, 6*c*).

This species is represented by a very rigid colony of an orange-brown colour, 45 millims. in height, 40 millims. in breadth, and about 10 millims. in thickness (fig. 5). It has a short sterile trunk from which three large lobes arise approximately in one plane. These lobes have the characteristic appearance of the previous two species; they are markedly flattened and bear the polyps mainly on the margin, but by a torsion in the plane of flattening the latter appear as if clustered terminally. In addition to the three large lobes there are also three smaller groups of polyps.

The whole colony is very stiff and rigid, and the central canal system is almost obscured by the densely packed spinose spindles. The surface, when viewed with a lens, is bright and glistening, and shows innumerable short, thick warty spindles interlocking in all directions.

The polyps occur chiefly on the margin; they are supported by truncated conical verrucæ about 2·5 millims. in height and 2 millims. in diameter at the top. The verrucæ are directed towards the upper portion of the colony, and are longer on the outer margin; they are built up mainly of longitudinally arranged spicules.

The anthocodiæ (fig. 7) are completely retractile; when fully expanded they are 4·5 millims. in length and 2 millims. in diameter. The "crown and points" arrangement of the spicules is not so definite as in the other species. On the stomodœal region the spicules are disposed circumferentially in 10-14 interlocking rows. In the upper portion, however, they gradually pass into an "en chevron" arrangement, so that eventually they form eight triangular groups, each consisting of 10–15 spindles with no very regular disposition. The diameter of the upper portion is slightly greater than that of the lower.

The tentacles, which are infolded over the oral opening, are 2 millims. in length and 0·75 millim. in breadth. On the aboral surface there is a distinct spiculation pattern. The triangular part corresponding to the main axis is closely covered with scale-like spicules arranged in pairs forming a V; these become smaller towards the tip, but the same arrangement is distinguishable throughout. The same pattern is continued into the pinnules.

The spicules of the trunk are short, thick spindles densely covered with rough warts. Those of the anthocodiæ are longer and narrower; they are thickly beset with spines or small warts. On the tentacles the spicules have an almost scale-like appearance, with slightly irregular edges; some are constricted at the middle. The following are some of the measurements of length and breadth in millimetres:—

A. Stalk and trunk—1·6 × 0·45; 1·2 × 0·4; 1 × 0·3; 0·6 × 0·15 (fig. 9*a*).

B. Anthocodiæ—1·2 × 0·1; 1·1 × 0·1; 0·8 × ·075; 0·5 × 0·05 (fig. 9*b*).

C. Tentacles—

(*a*) Scale-like—0·12 × 0·02; 0·06 × 0·02; 0·05 × 0·02 (fig. 9*c*).

(*b*) „ with constriction—0·08 × 0·03; 0·04 × 0·02 (fig. 9*c*).

Locality.—Andamans.

Another colony, 60 millims. in height and 18 millims. in maximum breadth, consists of a main stem, elliptical in section, with a maximum axis of 9 millims. and a minimum of 6·5 millims., surmounted by an irregular polyp-bearing portion. After a distance of 18 millims. the latter bends at an obtuse angle; after another 11 millims. it again resumes a direction almost parallel to the original course; and yet another flexion causes the whole colony to assume the form of a much-expanded W. At each bend a small lobe arises. The lowest is 14 millims. in length and 5 millims. in breadth at its origin; it is expanded laterally, and has a breadth of 9 millims. at the top. The second is 12 millims. in length and 11 millims. in maximum breadth; at its origin there is a twisting of the axis, and a small polyp-bearing excrescence arises on the opposite side. The fourth is 6 millims. in height, 8 millims. in breadth, and 4·5 millims. in thickness. Slightly below the level of the highest lobe the main axis becomes markedly flattened, and attains a breadth of 11 millims. and a thickness of 6 millims.

The cœnenchyma is very hard and densely spiculose; the surface is arenaceous in appearance, but on examination with a lens the distinct spicules may be seen irregularly arranged, and producing a translucent, shiny surface.

On the lobes and also on the main stem the polyps are disposed along the edge. The anthocodiæ are about 3 millims. in length and 2 millims in diameter; the spiculation is distinctly visible to the naked eye, and the white aboral surface of the tentacles is a marked feature.

Locality.—Arakan coast, 13 fathoms.

COMPARATIVE TABLE OF SPECIES OF CACTOGORGIA, N. GEN.

Species.	Nature of Stem and Stock.	Nature and Origin of Lobes.	Arrangement of Spicules of Polyparium.	Verrucæ.	Anthocodiæ.	Spicules.	Locality.
C. celosioides, n. sp.	Much flattened; stiff and rigid; with a translucent sheen; colour, light brown.	Flattened and bear polyps; origin indefinite.	Longitudinal.	Distinct; supported by longitudinally arranged spicules with apices projecting around the edge; occur along the margin of the colony.	Definite "crown and points" arrangement; "crown" consists of 7–10 rows of curved spindles; "points" each of one pair with occasionally one or two smaller ones between; tentacles bear numerous scales "en chevron" on the aboral surface.	A. Stem and stock — transparent spindles with multituberculate warts, 2·2 mm. × 0·55 mm. to 0·75 mm. × 0·3 mm. B. Anthocodiæ—spindles or clubs—0·95 mm. × 0·18 mm., 0·85 mm. × 0·1 mm. C. Tentacles— scales 0·07 mm. × 0·035 mm.	Andamans.
C. expansa, n. sp.	Cylindrical, stem with fan-shaped polyp-bearing lobes; densely spiculose and very rigid; very opaque in appearance.	As in *C. celosioides*.	Indefinite; interlocking in all directions.	Not very conspicuous; no definite arrangement of spicules; mainly on the margin of the lobes.	Definite "crown and points" arrangement; "crown" consists of about 8 rows of curved spindles; "points" made up of 6–8 pairs arranged "en chevron," and increasing in size from the base upwards.	Opaque, yellowish. A. Stem and stock — multi-tuberculated spindles, 1·5 mm. × 0·3 mm., 1·1 × 0·2 mm. B. Anthocodiæ—spindles and clubs, 0·8 mm. × 0·1 mm. C. Tentacles — pale yellow transparent scales, 0·04 mm. × 0·015 mm.	Off Cape Comorin, 38 fathoms.
C. alciformis, n. sp.	Much contorted, sinuous; antler-like; stiff and rigid; translucent.	Considerably flattened; arising mainly at the bends in the stock.	Irregular; interlock in all directions.	Fairly large; spicules disposed mostly longitudinally; occur principally on the margin of the flattened lobes.	Very large; spicular armature visible to the naked eye; "crown and points" arrangement not so definite; "crown" consists of 10–14 rows of curved spindles; in each triangular "point" there are 10–15 spindles, with no very regular disposition, but slightly "en chevron."	Transparent. A. Stem and stock — rough warty spindles, 1·6 mm. × 0·45 mm. to 0·06 mm. × 0·15 mm. B. Anthocodiæ — spiny or warty spindles, 1·2 mm. × 0·1 mm., 0·5 mm. × 0·05 mm. C. Tentacles—scale-like, 0·12 mm. × 0·02 mm. to 0·04 mm. × 0·02 mm.	Andamans; Arakan Coast, 13 fathoms.

EXPLANATION OF FIGURES.

Fig. 1. *Cactogorgia celosioides*, n. sp. Polyp (× 10).
" 2. " " Complete colony (× 2).
" 3*a*. " " Spicules from the stem.
" 3*b*. " " Spicules from the anthocodiæ.
" 3*c*. " " Spicules from the aboral surface of the tentacles.
" 4. *Cactogorgia alciformis*, n. sp. Polyp (× 10).
" 5. " " Complete colony (× 2).
" 6*a*. " " Spicules from the stem.
" 6*b*. " " Spicules from the anthocodiæ.
" 6*c*. " " Spicules from the aboral surface of the tentacles.
" 7. *Cactogorgia expansa*, n. sp. Polyp (× 10).
" 8. " " Complete colony (× 1¼).
" 9*a*. " " Spicules from the stem.
" 9*b*. " " Spicules from the anthocodiæ.
" 9*c*. " " Spicules from the aboral surface of the tentacles.

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SIMPSON. CACTOGORGIA.

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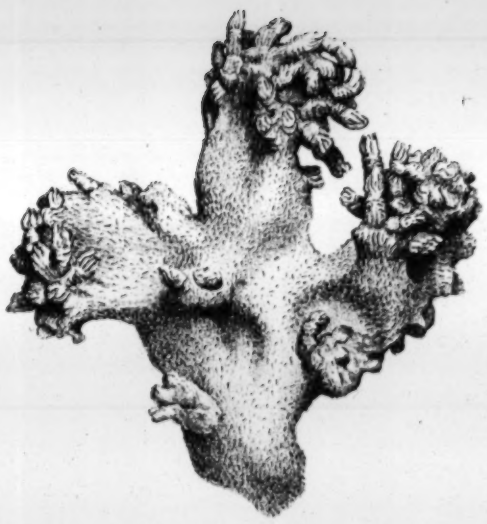

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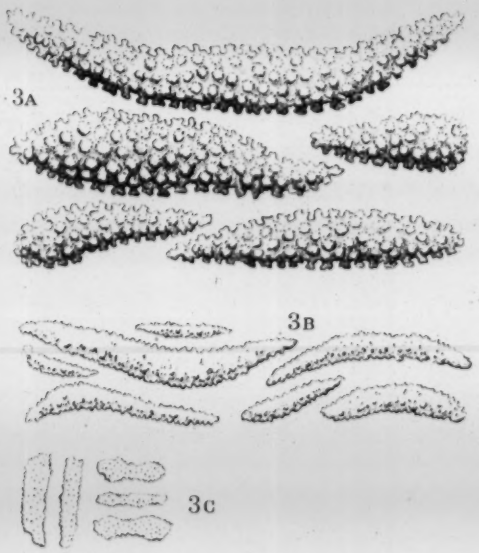

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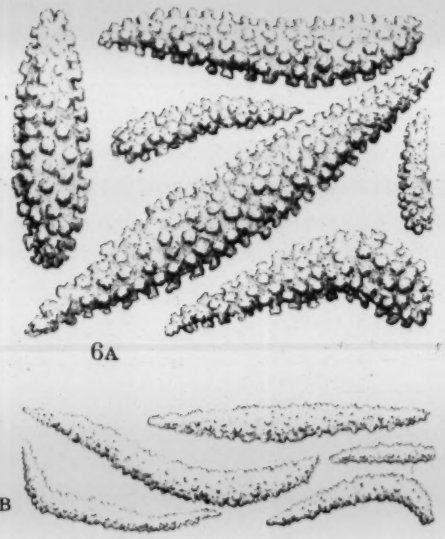

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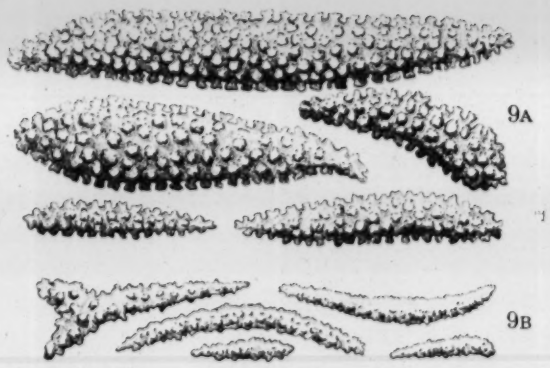

9A

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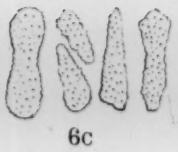

6C

9C

G. Davidson, del

E Wilson, Cambridge

XXXI.—Encystment of Tardigrada. By James Murray. (With Two Plates.)

(MS. received May 23, 1907. Read June 3, 1907. Issued separately September 5, 1907.)

Introduction.

The object of this paper is to discuss the recently discovered encystment of Tardigrada, as far as our imperfect knowledge permits; to compare the process with that observed in certain low groups of the Acarina, in which the Tardigrada are generally considered to have their nearest relatives; then to inquire whether these new facts throw any light on certain puzzling facts in the physiology of the Tardigrada and Acarina, such as the retrogression which produces the simplex forms of Tardigrada, and which is said to accompany each moult of the Acarina; and lastly, if they contribute anything towards settling definitely the systematic position of the Tardigrada.

That water-bears encyst themselves was first ascertained by Professor Lauterborn, and a short note on the subject was published in 1906 (21).

It is now known that the cysts of Tardigrada are extremely common, and there is reason to believe that various naturalists have seen them, though without recognising their true nature.

Professor Richters, in a recent letter, suggests that some of Spallanzani's figures might possibly represent cysts (35).

Spallanzani's original figures I have not seen, but they are reproduced by Schultze in his "Macrobiotus hufelandi" (34). Those figures are so crude that it is only by making large allowances that they can be accepted as Tardigrada. Fig. 5 on Schultze's plate, representing the ventral view of the animal, shows five pairs of limbs, each ending in a single strongly hooked claw, two pairs of limbs terminating the body in a manner hardly possible in any natural position of a water-bear. But, granting that they are Tardigrada, as Spallanzani's experiments, and the situation in which he found the animals, render reasonably probable, then the elliptical body represented in fig. 7 as reproduced on Schultze's plate might well be a cyst.

Schultze's own figures 2 and 3 might be cysts, or merely contracted examples.

Doyère probably had cysts in view when he wrote, in his *Mémoire sur les Tardigrades*, in 1840 (4) p. 308, "J'eus d'abord quelque peine à reconnaître l'animal, dans la petite masse, inert, en apparence granuleuse et amorphe que je rencontrais parfois à l'intérieure de certaines peaux qui me semblait abandonnées."

No one appears to have suspected the true nature of these amorphous objects.

I learn from Professor Richters that he had seen some of Professor Lauterborn's cysts in 1906. For some years these sausage-like little yellow packages had been

familiar to me, but I had merely wondered at them till, in the beginning of winter 1906–7, an opportunity occurred of seeing how they were formed.

The cysts which I found in great abundance were of quite different forms from the familiar yellow objects, and were not at first suspected of being Tardigrada.

After watching them for some weeks and ascertaining a very remarkable series of changes, a preliminary note on the subject was published in *The Zoologist* for January 1907 (25).

While this was in press, Professor LAUTERBORN's first short note on encystment reached me (21).

ENCYSTMENT OF M. MACRONYX.

Professor LAUTERBORN's account of the process is brief, but of great interest. He observed a water-dwelling species, *Macrobiotus macronyx*, DUJ. On page 267 he tells how he found, in many ponds around Ludwigshafen, skins of *Macrobiotus* which appeared to be filled by a single immense resting egg. He saw also, on one occasion, the body of a *Macrobiotus* loosen itself from its cuticle, and contract within it into an elliptical body, which then secreted a closely fitting envelope. Within this shell there was at first a feeble movement, which ceased in about an hour. The rods in the pharynx remained visible.

At first the cuticle of the beast remained connected with the cyst by numerous folds, but later it shrank more and more together, till finally the surface of the cyst appeared covered with a maze of spines and ridges, like some winter-eggs of Rotifers. The stomach of the animal observed was colourless, instead of golden-brown as usual. The thick skin was disposed in numerous transverse folds.

Professor LAUTERBORN does not remark on retrogression, simplification, or liquefaction of organs taking place within the cyst.

In a ditch near the pond where he found the animal which he actually observed to encyst itself, he saw many females of *M. macronyx* with their eggs deposited in the moulted skin.

Since the discovery that Tardigrada encyst themselves, Professor RICHTERS has had cysts of various species under observation, and has made some interesting discoveries, which will no doubt be recorded at an early date.

ENCYSTMENT OF M. DISPAR.

My observations were made on another water-dwelling species, *M. dispar*, MURRAY (25). This is, like *M. macronyx*, DUJ., a very large animal, attaining to nearly a millimetre in length. A lateral view of the animal is given in fig. 1.

It is hyaline and yellow or brown, with a pair of dark eye-spots. The teeth and pharynx are of the same type as those of *M. hufelandi*, RICHTERS, but differ in many

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details,—there is no "comma" in the pharynx,—the proximal end of the tooth has a very large "furca," the largest known in a tardigrade.

The claws are of a very distinct type, which is supposed to be that of *M. macronyx*. Each pair consists of two very unequal claws, united at the base, the longer claw strongly curved, and bearing at the back a strong bristle or supplementary point, which diverges from the main claw about a third of its length from the point, but can be traced down the back of the claw to its base. The lesser claws of the fourth legs are relatively much larger.

The eggs are spherical and are covered with little sharp conical processes, which do not touch at their bases. They are rare.

The species is common in Scotland, and has been found in England (York), Spitsbergen, and Franz Josef Land.

Professor Richters identified it at first as *M. macronyx*, but after the discovery of the egg he regarded it as a distinct species.

The two posterior dorsal processes, shown in fig. 1, vary greatly in size, and may be absent.

M. dispar had been known to me for a year or two before the cysts came to my notice. It had been found at the margin of Loch Tay, and in various ponds near Edinburgh and Glasgow.

The spiny egg had been seen on several occasions.

In the late autumn of the year 1906 I washed some moss from a shallow pond occupying an old quarry at Nerston, near East Kilbride, a few miles south of Glasgow.

M. dispar, not then named, was in very great abundance. No small examples were seen—all were large, and to all appearance full-grown, though there was no proof of full maturity, *i.e.*, no eggs were seen in the body. In one empty skin there was a spiny egg. I had hit upon the fortunate moment for observing them, as the great majority were in the act of casting their skins, and nearly all were at the same stage of the process—a very few had completed it or had not commenced. Even while I watched, many completed the moult, some leaving the old skin in the usual way, but most remaining in it.

The newly formed skin differed from the old skin; it was darker yellow, and dotted all over. The dots were probably pores from which a secretion exuded, as the surface appeared to be viscous, and extraneous matter adhered to it. The animal moved feebly and became gradually smaller; the amount of the secretion increased, and the adherent matter loaded the back with an umber-brown mass.

Still contracting and drawing in its legs, at the same time moving more and more feebly, it eventually became little more than half the original length, and assumed the appearance shown in fig. 2, which represents the cyst lying in the original skin.

At this stage it is quite rigid and dark-coloured, brown, purplish, or black. There is no appearance of extraneous matter, and the surface is even, but closely dotted. It is obscurely segmented, or divided by constrictions into four parts, which appear to

correspond to the four limb-bearing segments, the head and fourth legs being drawn in out of sight. There is a constriction in the centre of the body, and the anterior and posterior portions are very similar in form, but the posterior end is broader. There are deep constrictions towards each end, and the posterior one becomes important afterwards.

On the ventral side are six little conical stumps, the remnants of three pairs of legs (fig. 3). When the cyst has just been formed there are claws on those little stumpy legs, but after a short time it is found that they have been withdrawn through small openings at the ends of the legs (shown in fig. 3). I was never so fortunate as to witness the withdrawing of the claws.

The shagreening of the general surface continues on to the legs, but becomes more obscure towards the ends of the stumps, and the part surrounding the pores through which the claws are withdrawn is a clear membrane.

From the moment when it attains its final form, the skin of the cyst is brittle and so dark and opaque that its contents can only be dimly seen, and it is impossible to study the further developments within it. To do this it is necessary to break open the cysts.

When a cyst is broken open immediately after its completion, we find within it the animal much as it was before encystment, only smaller, and possessing all its organs, teeth, pharynx, claws, etc.

When a cyst is broken open at a somewhat later period, say after it has been formed for two or three days, the contained animal is found to have contracted and taken an elliptical form. The shagreened skin remains as an *outer case*, within which the elliptical body lies loosely.

The elliptical cyst (fig. 4) is covered by smooth, yellow, transparent skin, without trace of external limbs, but still containing a complete animal, having legs, claws, teeth, and pharynx.

The origin of this inner covering is puzzling. The *outer case*, which appears to be secreted from the skin, retains traces of the form of the animal. The *inner case* appears to be of quite a different nature, and looks like a true skin, having no dots or evidence of having been secreted, and no trace of segmentation or limbs. Yet, if not secreted, how account for the complete animal within it; and, if secreted, how account for its regular egg-like form?

The most remarkable part of the process follows. Cases broken open about a week after their completion are found to enclose the elliptical yellow cysts as before, but these no longer contain complete animals.

If the contents of a cyst can be squeezed out without rupture, there appears an almost amorphous mass, without trace of limbs, claws, teeth, or pharynx. It is unfortunate that the opacity of the outer case prevents the study of this remarkable change in its various stages.

Professor RICHTERS has now under observation some cysts of species which have not

the opaque outer case, and it is hoped that he will soon observe the sequence of the changes.

Seen within the *inner case* (fig. 4), the contained animal shows a faint segmentation, three transverse furrows dividing it into four nearly equal parts. When the animal is squeezed out no segmentation can be noticed (fig. 5). It is covered by a very thin cuticle and has a somewhat undulate outline.

Even in this latest stage, the animal has not lost every trace of its former self. The eye-spots persist as long as an animal has been watched, and the fat cells in the blood continue recognisable. There are also some cells, with dark contents, in the centre of the body, which I take to represent the stomach. The eye-spots become very large and diffuse, of loosely agglomerated granules (fig. 5).

Animals squeezed from the cyst at an early stage showed, as above remarked, no trace of limbs. At a later period, but at an unknown interval of time from the formation of the cyst, a squeezed-out animal had obtuse papillæ for limbs, without trace of claws (as shown in fig. 14). There was at this stage a very thin cuticle, and underneath it a lax cellular tissue of large obscurely polygonal cells. The supposed cells of the stomach, with brown contents, were still conspicuous; the fat cells were few; there was no trace of pharynx or teeth.

I have no observations between this stage and the final emergence, shown in fig. 12.

This was witnessed on several occasions, and is sufficiently curious. The animals were remarkably large and lusty, considering the enormous expenditure of material in making the various cases and integuments, and the small cyst from which they issued. They were fully provided with all the organs they possessed when entering the cyst; well-grown claws, pharynx, teeth, etc.

The case splits at the posterior constriction before alluded to, and the end portion opens like a hinged lid, permitting the animal to walk out backward. The emergence occupied several hours, and after a severe struggle and the extrication of one pair of limbs, the animal would take a long rest before recommencing the struggle. Fully emerged, the creature did not appear greatly smaller or conspicuously different from what it was originally.

The process of encystment, as observed in *M. dispar*, and described above, differs in many respects from that sketched by Professor Lauterborn, yet there are many points of correspondence. *M. macronyx* and *M. dispar* are the only two species yet observed which secrete a special *outer case*. Those two species are of aquatic habit, while all others of which I have seen cysts are normally moss-dwellers.

Cysts of Other Species.

Cysts of a good many species of Tardigrada have been seen, but I have had no opportunity to study any of them except *M. dispar*.

All the cysts which I have seen are a good deal alike, and none of them, except

M. dispar, had the special *outer case*. They are elliptical bodies, usually dark yellow in colour, but sufficiently transparent to allow the internal organs to be seen. Their surface is less regular than that of the *inner case* of *M. dispar*, with which they seem to be homologous; it is usually more or less wrinkled, and the wrinkles form a regular pattern, as in the cyst of *M. echinogenitus* (fig. 16*a*).

M. echinogenitus, RICHTERS.—Cysts were abundant in moss brought from Spitsbergen by Mr WM. S. BRUCE in August 1906. One cyst was found in a bog pond on Blantyre Moor, near Glasgow. In neither case did I notice any reduction of the internal organs. The example figured (fig. 16*a*), which I identify as *M. echinogenitus* by its claws, was found in a pond at Nerston, near Glasgow. It was empty when found, and is figured to illustrate the symmetrical wrinkling of the surface, which differentiates the cyst from an ordinary skin. Professor RICHTERS has sent me a photograph of the cyst of *M. hufelandi*, which appears to be wrinkled in a similar manner.

Claws were attached to this cyst, which rarely occurs, in my experience.

M. oberhäuseri, DOY.(?)—Two different cysts of animals resembling this species, but not positively identified, are figured. Fig. 15 is an oval cyst, narrowed towards the posterior end, with a smooth, unwrinkled skin, and the internal organs not reduced. The pharynx is quite like that of *M. oberhäuseri*, but the two pairs of claws are not so dissimilar as in that species.

Fig. 17 shows a slightly larger cyst, wrinkled, and not narrowed to one end. The claws are as in *M. oberhäuseri*, but the pharynx differs slightly, the second rod being slightly longer than the first (an unusual condition), and there is a comma.

Diphascon.—Cysts of this genus have been seen, but I have no notes throwing any light on this subject.

Echiniscus.—Cysts of this genus have long been known to me, but not being aware of their nature, no study was made of them. Since beginning the investigation of encystment, many cysts of one species, *E. arctomys*, EHR., have been found in moss from Uganda, sent to me by Mr N. D. F. PEARCE, of Cambridge. These cysts were similar to those of *Macrobiotus*, elliptical, and without limbs or processes. The contained animal was red.

E. perarmatus, MURRAY (27).—This species, recently discovered among moss sent to me by Mr WM. MILNE of Uitenhage, Cape Colony, is a common species in South Africa. In moss received from Mr MILNE in April 1907, I found several cysts. One is figured (Plate I. fig. 6). It is elliptical, and lies loosely within the ordinary skin of the animal. There is no *outer case*, as in *M. dispar*. There is no trace of external limbs on the cyst, and when subjected to pressure, it was found that there were within the case no limbs, pharynx, or other recognisable organs. The cyst is filled by a dark red granular mass, almost opaque, and in the centre is a darker, umber-brown tract (stomach ?).

Encystment of certain Acarina.

The account published by Michael in 1901 (23) of the encystment of certain Mites, of the family Tyroglyphidæ, indicates such a close correspondence with the process as observed in *M. dispar*, that it is thought desirable to give a pretty full account of it here.

The Tyroglyphidæ (or Cheese Mites, etc.), like most other Acarina, undergo a distinct metamorphosis, passing through the stages of *larva* and *nymph* before reaching the adult condition. They cast the skin three times before becoming adult, once in the larval state and twice as nymphs. In the course of growth they do not greatly alter in form, so that the species at the different ages is generally easily recognised; but the full complement of limbs is only acquired when the larval skin is thrown off, and the young nymph more nearly resembles the larva, while the old nymph (after the first nymphal moult) is more like the imago.

It has long been known that many Tyroglyphidæ have an immature condition in which there are special adaptations to assist distribution, and earlier authors founded on these immature forms the genera *Hypopus* and *Homopus*. These hypopial nymphs are active, but are said to be able to exist for a long time without food, and to survive great heat and drought.

Seeking for the hypopial nymphs of certain species of the genus *Glycophagus*, Michael discovered the rudimentary *hypopi*, of which the encystment so resembles that of *M. dispar*.

Michael (23), on p. 168, etc., tells how he found inert nymphs of *Glycophagus domesticus*, which had the cuticle thicker, whiter, and more opaque, the skin of the legs empty. These "cases," which are simply nymphal skins under peculiar conditions, contained each a protoplasmic mass, of the general form of a *Hypopus*, but without trace of legs, mouth, or other external organs. It was covered by a transparent, colourless, and almost structureless cuticle, and was rounded behind, and bluntly pointed in front.

Michael saw immature *G. domesticus* emerge from the cases "which did not split irregularly like ordinary nymphal skins, but usually opened by the posterior end of the case, which had been concave, being pushed out so as to become convex; and separating from the lateral and ventral parts of the case, but remaining attached to the dorsal. The cases, although open, were not entirely empty; I found that each contained a cast skin."

The nymphs which emerged from the cases became inert in about a week, and a few days later adults emerged. "It was thus ascertained that the cases were a penultimate-nymphal stage, *i.e.* the nymph which emerged from the case became adult at the first ecdysis."

A sketch copy of Michael's figure of the case containing the rudimentary *hypopus* is given in Plate II. fig. 18*a*, and fig. 18*b* shows the hinged lid by which the nymph emerged.

Encystment of Tardigrada and Acarina Compared.

In the foregoing accounts of the encystment of *Macrobiotus dispar* and *Glycophagus domesticus* there are many points of correspondence, as well as some important differences.

The essential points of agreement are the formation, within an ordinary skin of the animal, of an inert protoplasmic mass, protected by a peculiar skin, and which has lost by retrogression all trace of external organs, and apparently of most of the internal organs, and the final emergence, by the opening of a posterior trap-door in the case, of an animal having the full complement of organs.

The chief difference is that the case of the Mite is a real skin, that of the Tardigrade appears to be merely a dense secretion from the skin. This is not, however, demonstrated, and the *outer case* of the cyst may consist of a real skin, as well as the secretion. The reason for thinking that it is a secretion only is the withdrawal of the claws, which in ordinary changes of skin are thrown off with the rest.

Even if the case is only a secretion, there is the original skin of the animal to correspond to the hypopial case of the Mite, as encystment is always preceded by an ordinary moult.

The Mite is known to encyst, when it does so at all, at a definite stage in development, immediately before attaining to maturity. The Tardigrade is judged from its size to be full grown, but this also is not yet demonstrated, and it may be that here also it occurs at the corresponding stage of development, just before reaching sexual maturity.

Simplex Forms of Tardigrada.

We may now inquire whether the phenomena of encystment throw any light on the puzzling questions of *simplex* forms. As a simplification of the Tardigrade takes place during encystment, is it possible that the simplex forms are connected with this process?

Simplex forms are very common. They are known in nearly every species of *Macrobiotus*, in several of *Diphascon*, and it is likely that all Tardigrada possess them.

The name was given to them by Richters (31), in recognition of the fact that Plate's *Doyeria simplex* was nothing but a peculiar condition of some species of *Macrobiotus*.

The peculiarity of the simplex form is the reduction of the manducatory apparatus. The teeth are reduced in size, have no furca or bearers, and are simply little, straight, pointed stylets, which do not even reach the mouth or gullet, and therefore cannot be functional. The rods in the pharynx are usually quite abortive; the gullet becomes a very slender tube (fig. 7). This is the usual simplex state, but the reduction may go further, and the teeth, rods, gullet, and mouth may totally disappear; and though in these cases the muscular bulb of the pharynx usually persists, that is occasionally also

absent, and there is then no trace of the alimentary canal in front of the stomach (fig. 8).

This condition is found in large and strong animals, which have the appearance of having plenty of food in the stomach. I have seen no trace of reduction of any other organs. Simplex forms of several species have been seen in the egg.

I have very frequently noticed that animals in this condition were about to moult, though I doubt if this is invariably the case.

Richters (31) regards them as parallel forms, and thinks that some species at least (e.g., *M. hufelandi*) have peculiar forms of eggs from which the simplex individuals come.

The fact that the most fully reduced individuals have no anterior opening to the alimentary canal convinces me that the state is temporary. The alimentary canal is a *cul-de-sac*, opening only by the anus, and it is impossible that they can imbibe food.

As it is definitely known that some species at least undergo simplification in the course of encystment, it may be supposed possible that the simplex individuals may be about to encyst, or may just have emerged.

M. dispar retains all the parts of the manducatory apparatus till the inner case of the cyst is formed, and in the same species the individuals which were seen to emerge naturally from the cysts had also all their organs.

If this is the normal course in other species, we can only connect the ordinary simplex form with encystment by supposing that the absorption of the organs had been prematurely stimulated, or the moult and encystment somehow retarded.

The Moulting of Acarina.

A somewhat analogous simplification has been observed among certain of the lower Mites.

When moulting, these Mites become inert for a time, and return partially to an amorphous condition. Michael (23), p. 180, etc., quotes various authors who have written on the subject.

Gudden (18), p. 284, writing of certain parasitic Sarcoptidæ, states that at the moult the whole of the inner parts of the creature return to an amorphous mass, like the egg; and that from this the new creature is formed, as from an egg.

Megnin (22), p. 214, confirmed this view, and believed that at the ecdysis in all Acarina, all the internal organs liquefied and formed a sarcodic plasma, having a true blastoderm, which sprouted like that of an egg.

By this theory it appears almost as if the whole substance of the animal went to form a single egg.

Michael (23), p. 181, says that this theory has now been shown to be incorrect, "and that the return to a more or less amorphous condition is usually, and probably always, confined to the soft parts of the legs and trophi, and what may be described as appendages or external organs."

It is proven to be incorrect in various groups, so that MEGNIN's wide generalisation breaks down; but, considering the different extent to which retrogression goes during the hypopial encystment of such closely related species as *Glycophagus domesticus* and *G. spinipes*, it seems to me that each species must be independently investigated, and that it is not improbable that the change may go so far in some species as to reduce them to almost as simple a condition as an egg.

It may be that the reversion to an amorphous condition which GUDDEN and MEGNIN believe to accompany each moult, and the encystment in the penultimate-nymphal stage described by MICHAEL, may be simply different interpretations of the same facts.

THE MOULTING OF TARDIGRADA.

That Tardigrada cast their skins was known to GOEZE, the first naturalist who has recorded an observation of a Water-Bear. Most subsequent observers have confirmed the observation, and many of them noticed that some species deposited their eggs in the skin which they cast.

C. A. S. SCHULTZE is the first naturalist, so far as I know, who has paid any attention to the number of moults, and the only one who claims to have followed an individual from birth to death. He states (34), p. 4, that *M. hufelandi* moults twice, lays its eggs after the second moult, then dies. It must be remarked that an animal studied in this way cannot be under its normal conditions, and death might be premature.

DOYÈRE (4) gives a minute account of the casting of the skin, and says that the epithelium of the alimentary canal is also cast, as may be seen at both ends of the canal when the animal contracts greatly within the old skin. He states that they moult several times, but admits that he never watched an individual throughout life, and cannot state the number of moults.

I can find no one else who has even considered the question of the number of moults, though several have carefully studied a simple moult.

LANCE (20) considers DOYÈRE's observations and conclusions as incorrect in many particulars. He regards DOYÈRE's account of the shedding of the chitinous lining of the gullet and cloaca as greatly exaggerated, and on p. 44 he quotes ERLANGER (12) to show that a portion of the ectoderm is included in the anal invagination, and supposes that it is this part only, really belonging to the ectoderm, which is shed with the outer skin.

Except in the genus *Echiniscus*, no Tardigrada are known to undergo any metamorphosis. They are hatched in the final form and simply increase in size and attain to sexual maturity. On this account it would only be possible to ascertain the number of moults by watching the individual throughout life. In the Acarina, where each moult is characterised by a greater or less change of form, it is a simpler matter to count the moults.

The metamorphosis in the genus *Echiniscus* is a very slight thing. The larvæ are

hatched with only two claws on each leg, while the adults have four. They have sometimes also fewer or shorter setæ or other processes. They attain the four claws very early, probably at the first moult, and while still quite small. Unlike the Acarina, the larvæ have the full adult complement of limbs.

I have seen an individual of *E. granulatus*, Doy., which had been unable to completely throw off the old skin at the moult, and it remained adherent till the next moult. It was thus possible to compare three stages of the same individual. In these two moults there was very little increase in size, but some of the processes elongated considerably, and the straight spines on the outer claws increased in number.

There must in this case have been at least three moults—the one when it ceased to be a larva, and the two actually observed; but as the animal when first seen was very much larger than the larva, it is certain that there must have been one or more intermediate moults.

The rigid skin of *Echiniscus* may require to be more frequently cast than the softer skin of *Macrobiotus*, and Schultze may be right about the two moults of *M. hufelandi*.

The female does not ordinarily die after casting her skin and laying her eggs. One species at least carries the eggs about till they are hatched, and continues to live for some time after, though I have never been able to keep an individual under observation till a second lot of eggs was developed. On the whole, I am inclined to think that even after maturity the skin is changed more than once, and successive clutches of eggs are laid.

During encystment some species cast off at least three and possibly four coats, but these may not be true skins.

Systematic Position of Tardigrada.

The systematic position of the Tardigrada has given rise to much controversy. The only point on which there is general agreement is that they are Arthropoda, Dujardin alone among prominent naturalists assigning them a lower place—with the Rotifers in his class of the Systolides—an opinion which he afterwards modified.

It is not intended here to enter into the whole question, but merely to give a sketch of the history of the controversy, and to enquire whether the phenomena of encystment bring it any nearer settlement.

O. F. Müller (24) in 1785 first gave a scientific name to a Tardigrade, *Acarus ursellus*, which he thus included among the Acari. Müller's view is accepted by Gmelin, 1788, (13), Dutrochet, 1837 (9), Kauffmann, 1851 (19), etc. Schrank, 1804 (33), also put them near the Acari, in his *Insecta Aptera*, between *Pulex* and *Acarus*.

They were regarded as true Insects by Dutrochet in his earlier work, 1812 (8), Blainville, 1826 (2), etc.

They were reckoned among Crustacea by Nitzsch, 1820 (28), Schultz, 1834 (34), Ehrenberg, 1834 (10), Perty, 1834 (29), etc.

Other opinions had fewer adherents. DUJARDIN, 1841 (6), united them with the Rotifers to form his class of Systolides, a classification hardly accepted by anyone except DOYÈRE, 1840 (4), who afterwards abandoned it. DUJARDIN himself, in 1851 (7), admitted that they could not be classed with Rotifers, but contends that neither are they near the Acari.

GRAFF (15) makes a special order, Stelechopoda, of the Myzostomida, Linguatulida, and Tardigrada.

PLATE, 1888 (30), regards them as the lowest of the Tracheata, near the Onychophora.

LANCE, 1896 (20), places them between the Worms and the Tracheata, in the Protracheata, near *Peripatus*.

GREEFF, 1865 (17), admits that the general opinion places them with the Acari, and gives reasons against doing so, without committing himself to any more definite opinion.

BASSE, 1905 (1), denies any close affinity with *Peripatus*, and places them again in the Tracheata.

The fact that so many good zoologists have supported such different views of the affinities of the Tardigrada appears to indicate that their essential structure does not incline very markedly to any one group of the Arthropoda more than another. They form themselves a very distinct group.

This being so, such subordinate characters as the possession of four pairs of limbs, the absence of distinct abdomen, and the simplicity of the circulatory and respiratory arrangements, gain weight in indicating an affinity with the only other Arthropoda similarly characterised, viz. some of the lower Mites.

That the affinity is not really very close is, I think, indicated by the fact that, although the adults possess four pairs of limbs, they do not, like the Acari, at any stage in their development possess only three pairs.

We find among Tardigrada and certain Acarina a retrogression occurring at a certain stage in development, or under certain conditions, which results in an encystment having a marked analogy with that of such common occurrence among Protozoa (with which MEGNIN compares it), and which, outside of these two groups, has no known parallel among animals higher than the Protozoa.

The remarkable coincidence of even the secondary details of the process in *Macrobiotus dispar* and *Glycophagus domesticus*, even to the final leaving the cysts by a trap-door, can hardly be regarded as other than fortuitous.

The essential part of the process, however,—the formation of cysts, within which the animals return in a greater or less degree to an amorphous condition,—seems to me to strengthen the belief that there is a real affinity between the two groups.

Conclusions.

What purpose does encystment serve in the life-history of the Tardigrada? Encystment, if not accompanied by absorption of organs, might be regarded as simply a sort of hibernation. This view of its meaning is supported, in the case of *M. dispar*, by the fact that the encystment took place in the beginning of winter, just when the shallow ponds in which the animals live were beginning to skin over with ice on cold nights.

On the 18th November 1906 the pond was completely frozen over in the morning. At 11.30 A.M. there was open water at one side, having a temperature of 39°·0 F. At the other side the surface was still covered by ice, and the temperature under the ice was 36°·0. In moss taken from under the ice there were many Tardigrada (*M. dispar*) beginning to encyst. Later in the season, when the pond was frozen nearly to the bottom, the ice was broken and moss adhering to it washed. There were now numbers of cysts, but no active animals. When this moss had been kept in a warm room for a number of hours, active animals began to appear, and it was then that the emergence from the cysts was studied. In the course of a day or two the active animals became very numerous. These facts might indicate that the process is nothing but a hibernation. But the return to a simpler condition puts another aspect on the matter. In what way can it benefit a hibernating animal to absorb its legs and other organs, and afterwards grow a new set of them? There is surely waste here, while in the familiar instances of hibernation, physiological activity is so low that waste is reduced to a minimum.

Is there, then, in this absorption and regeneration of parts anything analogous to the rejuvenescence of lower forms? Does the animal retain its individuality throughout these changes?

If Megnin were right in his theory, that the sarcodic plasma formed during the ecdysis of Acarina was enveloped by a veritable blastoderm, the process might be considered a reproductive one.

In the Tyroglyphidæ studied by Michael the gradation which may be traced from species which have an inert, amorphous cyst, similar to that of Tardigrada, to those more closely resembling the nymph, and having rudimentary limbs, makes it clear that the cyst is merely a stage in the development of the individual, and by analogy we may suppose that this is the case with Tardigrada also.

The ordinary, active hypopi of the Tyroglyphidæ are adapted to secure distribution. Megnin suggests that the nymphal skins containing the cysts might be blown about by the wind, but Michael does not see why this should not as readily occur with ordinary inert nymphs before the ecdysis.

However it may be with Acarina and with Tardigrada living among terrestrial moss, the encystment of *M. dispar* cannot be supposed to assist distribution. It is an

aquatic species, living in shallow still water, and in the place where it was studied the cysts remained in the moss where they were formed, under the ice.

MEGNIN believed that the change of a nymph into a hypopus was caused by unfavourable conditions. MICHAEL thought it had no connection with unfavourable conditions.

With regard to the Tardigrada, I believe the evidence goes to show that the encystment is induced by unfavourable conditions. It may be the low temperature which is the unfavourable condition for aquatic forms, and the drying of the moss in the case of the terrestrial forms. The encystment of Protozoa appears to be frequently induced by adverse circumstances, though it may have other causes.

Further investigation will be necessary before it will be possible to draw any more definite conclusions as to the meaning of the encystment of Tardigrada.

NOTE ON M. MACRONYX, M. DISPAR, AND RELATED SPECIES.

M. macronyx and *M. dispar* appear to have much in common, although, if the two modes of disposing of the eggs really differentiate natural groups, they would be placed in different sections of the genus, or in different genera, if *Macrobiotus* were subdivided on that character.

I believe, however, that there has been much confusion over *M. macronyx*. Special biological studies have been made by men little acquainted with species, on animals supposed to be this species, and till quite recently few supposed that there were numerous species of Tardigrada. *M. macronyx* was supposed to be the only fresh-water species; therefore any species found in water must, it was thought, be that species.

M. macronyx, DUJ. (7), is very insufficiently described. DUJARDIN'S first description of the Tardigrade, published in 1838 (5), applies to an animal which he afterwards, in 1851 (7), named *M. lacustris*. The earlier description is of little value, as it undoubtedly confounds two or more species. He figures two sets of claws, totally distinct,—fig. 6 (5) shows claws which, I think, may be taken as like those which he (in 1851) ascribed to *M. macronyx*,—fig. 7 shows claws of the same type as *M. oberhäuseri*, DOY.

The description of *M. macronyx* given in 1851 (7), p. 163, is far from satisfactory. The animal is 1 mm. long, and the long claws are $\frac{1}{20}$ mm. long. The manducatory apparatus (mouth, teeth, gullet, and pharnyx) is nearly $\frac{1}{4}$ of the total length.

The pharynx forms half of the length of the manducatory apparatus. The mandibles (teeth) are larger and more curved than in *M. lacustris*, and are *not bifurcate* at the base. Of the eggs he says nothing.

As to the teeth, *not bifurcate* at the base, I have seen no *Macrobiotus* without a tooth furca, unless when in the *simplex* state; and, moreover, DUJARDIN shows a furca in his fig. 7.

Leaving that character aside, the animal is characterised by the peculiar form of

claws, the large size, and the habitat in water. The pharynx is figured with three slender rods, of which the first is longest.

M. dispar agrees closely with this description, except as to the pharynx, in which the first two rods are joined. It has a spiny egg (Plate I. fig. 11).

Another species, having the same type of claws, *M. ambiguus*, Murray (Plate I. fig. 10) (26), and resembling *M. dispar* in all other characters, has also a spiny egg.

M. furcatus, Ehr. (11), another large species having claws of the *macronyx* type, likewise has a spiny egg (fig. 11*b*).

Considering that all the species known to me having claws of this particular type also had spiny eggs, and that Dujardin makes no mention of the egg of *M. macronyx*, I would have been inclined to recognise the animal which I have called *M. dispar* as the type of *M. macronyx*, and would have amplified the description by ascribing to it spiny eggs.

Various authors have, however, professed to recognise *M. macronyx* in an animal which lays smooth eggs in the cast skin.

Greeff, in 1866 (16), p. 120,—Plate, in 1888 (30), p. 536,—Lance, in 1896 (20), p. 204,—Lauterborn (21), in 1906,—Richters, in 1904 (32), p. 63, ascribe to the animal smooth eggs which are deposited in the skin at the moult. Greeff and Lance figure claws which agree with Dujardin's figures of *M. macronyx*.

Richters (32), p. 63, ascribes to Doyère the assertion that the eggs are laid in the cast skin; but as Doyère's paper appeared in 1840, and *M. macronyx* was described in 1851, Doyère can only be referring to Dujardin's unnamed Tardigrade of 1838, afterwards called *M. lacustris*.

Greeff (16), p. 105, probably originated the belief that *M. macronyx* laid the eggs in the skin by identifying *M. lacustris* as the young of *M. macronyx*, an absurdity on the face of it, as *M. lacustris* was said by Dujardin to lay the eggs in the skin, and he made no such assertion about *M. macronyx*.

It is not clear how far these various authors had for themselves verified the fact of the laying of smooth eggs in the skin, in association with claws of the *macronyx* type, or whether they were in some cases repeating statements made by others.

Professor Richters has sent me preparations of *M. macronyx*, which agreed fully with *M. dispar* as to claws and pharnyx, but it was not demonstrated that the actual individuals mounted had either come from, or had deposited, smooth eggs.

In this unsatisfactory state of affairs, and in view of the large body of authority for the belief that *M. macronyx* lays smooth eggs, I judge it best in the meantime to retain *M. dispar*, though having a strong suspicion that it will prove to be Dujardin's *macronyx*.

The species observed by Professor Lauterborn, whether it be the true *macronyx* of Dujardin or not, was at any rate a species which he believed to lay the eggs in the skin at the moult, and therefore quite distinct from that studied by me.

Note—Correction of Name.

Macrobiotus furcatus, Murray.

This name was given to a species collected by the Scottish National Antarctic Expedition in the South Orkneys ("Tardigrada of the South Orkneys," *Trans. Roy. Soc. Edin.* xlv., 1905, p. 327, Plate II. figs. 6*a* to 6*d*). I was then unaware that Ehrenberg had already used the name for an Alpine species in 1859 (11). *M. furcatus*, Ehr., appears to have escaped the attention of all subsequent writers on Tardigrada whose works I have been able to consult. My error was pointed out by Professor Hay of Washington, and I now correct it and give the species another name.

Macrobiotus furciger, n. sp. (Murray) (= *M. furcatus*, Murray).

Description.—Large (up to 600μ), hyaline. Claws of each pair united for about half the length of the larger claws; supplementary points very strong. Teeth strong, curved; gullet wide; pharynx shortly oval, with conspicuous apophyses on end of gullet, and three equal, separate rods in each row of thickenings, besides a large comma. Eggs spherical, spiny, about 83μ in diameter without the spines, 105μ over the spines; spines with bulbose bases, tapering upwards, and once, twice, or thrice forked at the tips; a circlet at the base as in *M. hufelandi*, Richters.

As remarked in the original description, this is the South Orkney representative of *M. hufelandi*. The most obvious distinction is the dichotomous processes of the egg, those of *M. hufelandi* ending in expansions, which may be likened to little funnels or discs. There are normally three distinct rods in the pharynx, while in *M. hufelandi* the two rods next the pharynx are normally joined, and when separate they remain close together or actually in contact.

Professor Richters has recently seen reason to believe that the rods in the pharynx of *M. hufelandi* vary greatly, and that there may be three quite distinct; he also finds that the degree of union of the claws varies so much as to offer a complete series from the V-shaped pairs of *M. echinogenitus* to the closely welded pairs of typical *M. hufelandi*.

My experience of Scottish examples has not yet confirmed Professor Richters' observations on those points, but has rather led me to regard most of the structures of Tardigrada as fairly constant. Species do, however, vary more in some regions than in others.

In the large numbers of examples of *M. furciger* examined I have never seen the first two rods in the pharynx united, nor an egg spine unforked. As no typical examples of *M. hufelandi*, nor of its egg, were found in the South Orkney collections, and as all the characters of *M. furciger* were very constant, it seems to me that, after

making all due allowance for variation, we must regard it as a good species, though closely related to *M. hufelandi.*

M. furciger, MURRAY, has no affinity with *M. furcatus*, EHR., which is related rather to *M. dispar*, MURRAY, and *M. ambiguus*, MURRAY.

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EXPLANATION OF PLATES.

Plate I.

1. *Macrobiotus dispar*, Murray. Side view.
2. ,, ,, cyst in the old skin.
3. ,, ,, oblique ventral view of cyst.
4. ,, ,, cyst, with outer case removed.
5. ,, ,, *simplex* animal squeezed out of cyst.
6. Cyst of *Echiniscus perarmatus*, Murray.
7. *Macrobiotus nodosus*, Murray. *Simplex* form.
8. ,, ,, further reduced state.
9. *M. dispar*, *diphascon-simplex* form.
10. *M. ambiguus*, Murray. Portion of surface of egg.

11*a*. *M. dispar*, portion of surface of egg.
11*b*. *M. furcatus*, Ehr. Portion of surface of egg.

Plate II.

12. *M. dispar*, emerging from cyst.
13 ,, empty case, with its trap-door.
14. ,, simplex individual, showing rudimentary limbs.

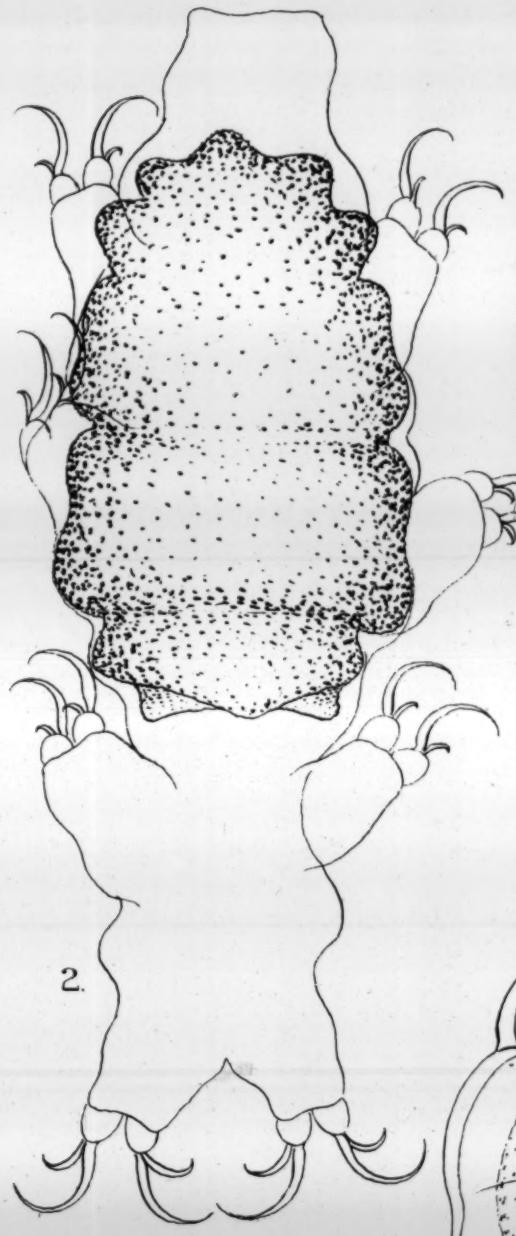
15*a*. *M. oberhäuseri*, Doy.? Cyst in skin.
15*b*. ,, teeth and pharynx in cyst.
15*c*. ,, one pair of claws.

16*a*. *M. echinogenitus*, Richters. Wrinkled cyst.
16*b*. *M. echinogenitus*, a pair of claws.

17*a*. *M. oberhäuseri*, Doy.? Wrinkled cyst.
17*b*. ,, teeth and pharynx.
17*c*. ,, a pair of claws.

18*a*. *Glycophagus domesticus*, De Geer. Rudimentary *Hypopus* (after Michael).
18*b*. The same. Posterior part of case, with its trap-door. (Compare 13.)

MURRAY: ENCYSTMENT OF TARDIGRADA.—PLATE I.



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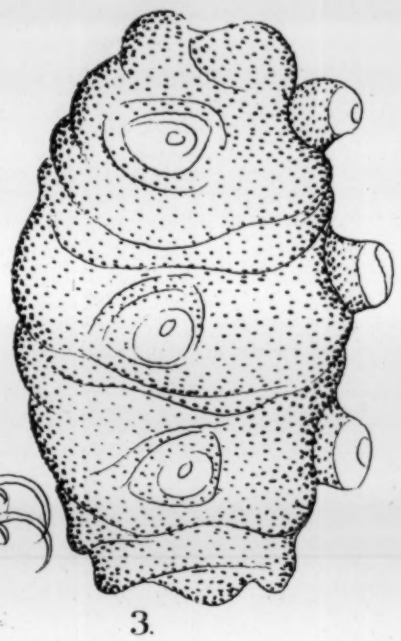

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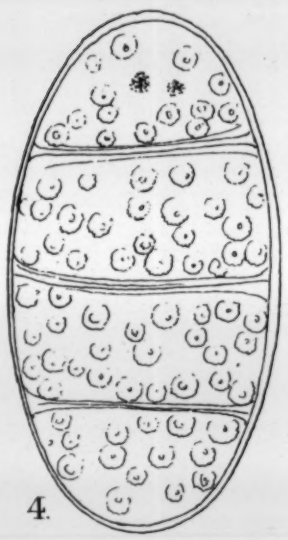

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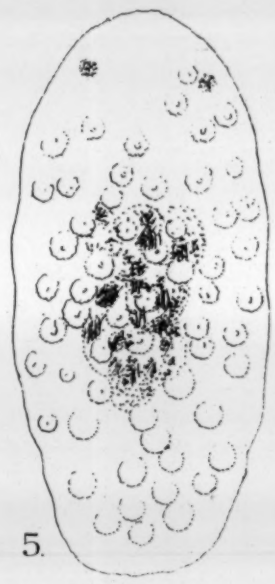

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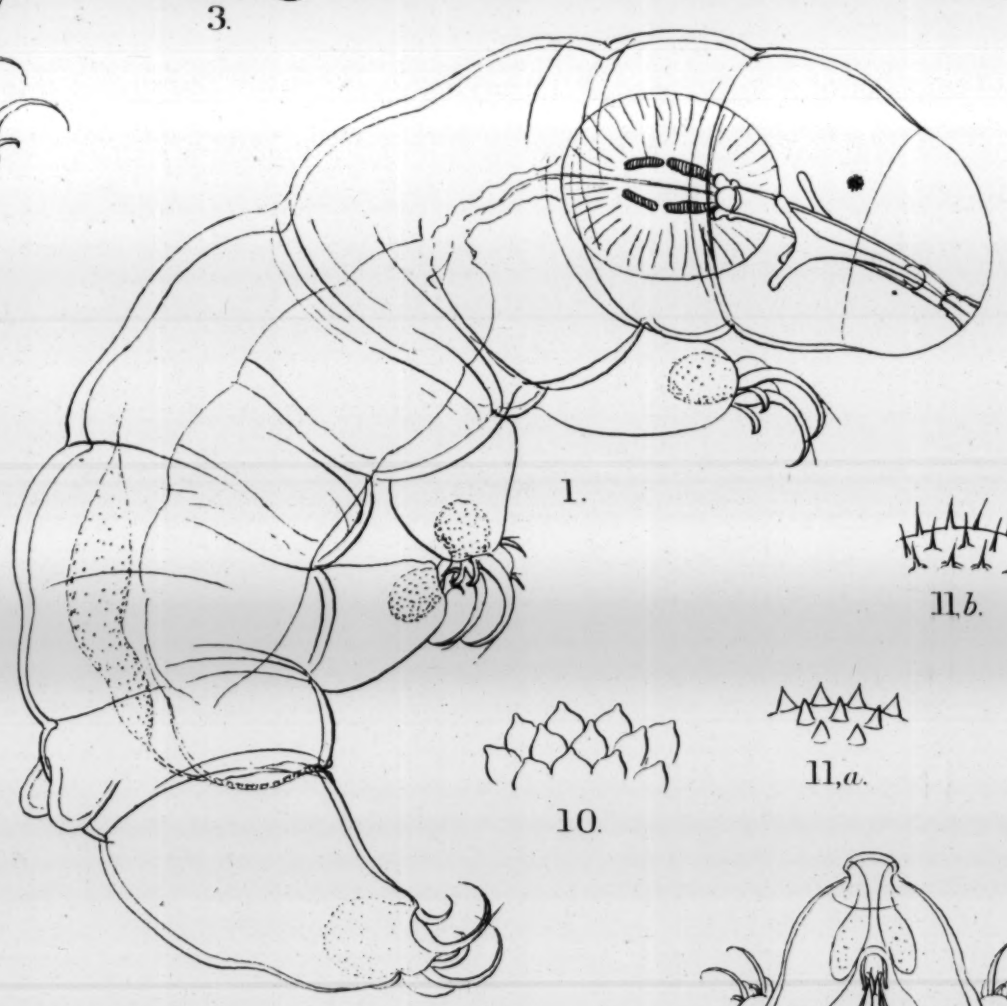

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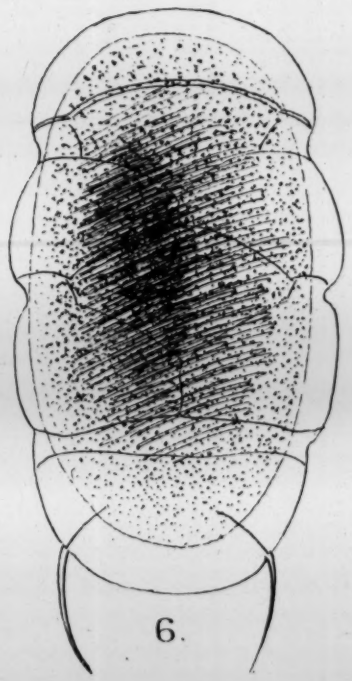

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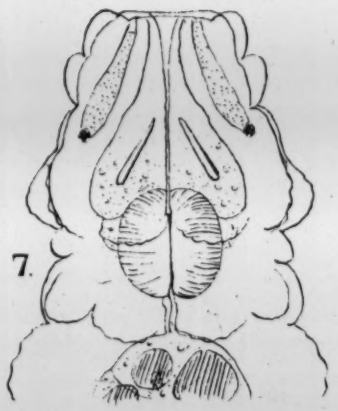

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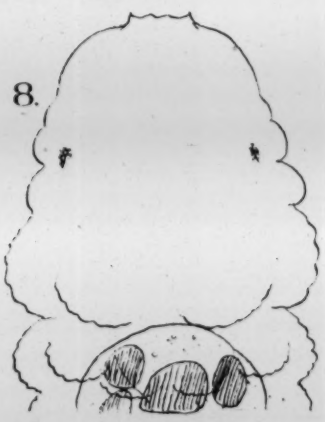

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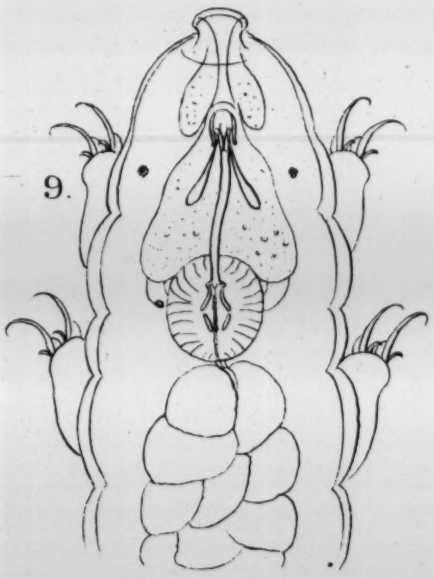


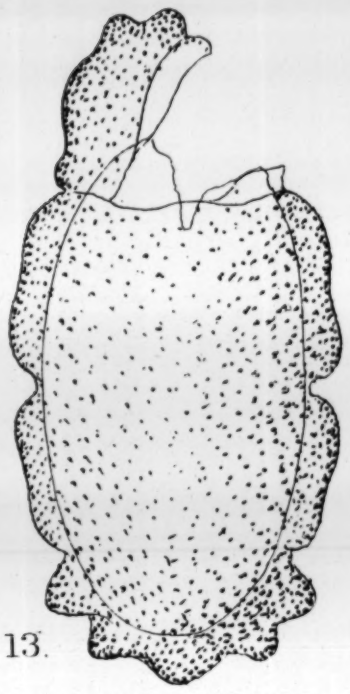
9.

10.

11,*a*.

11,*b*.

MURRAY: ENCYSTMENT OF TARDIGRADA.—PLATE II.



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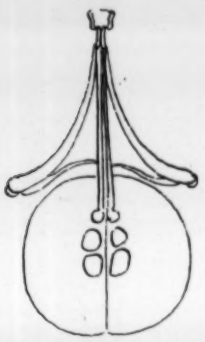

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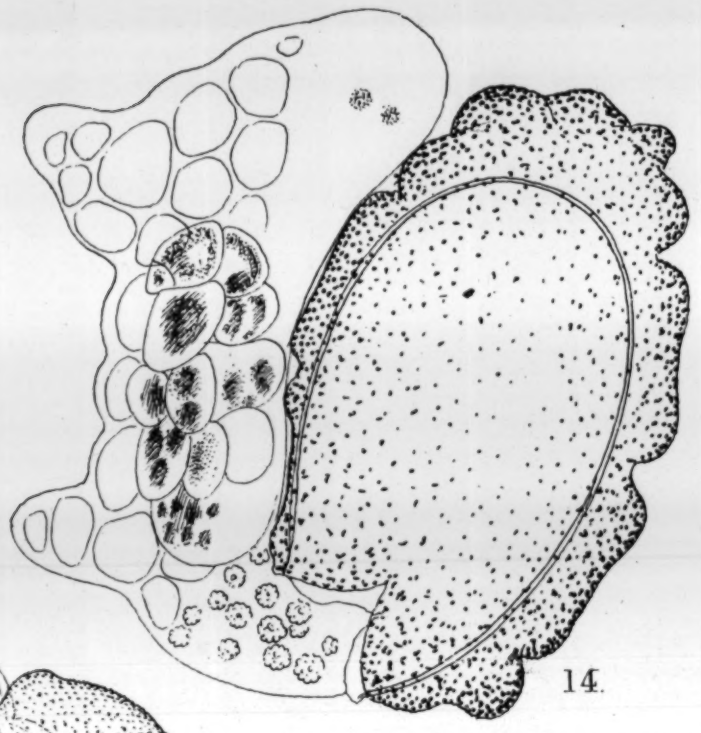

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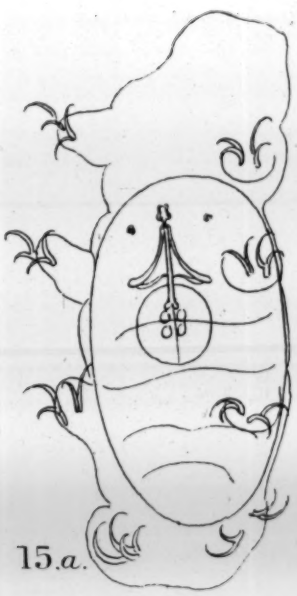

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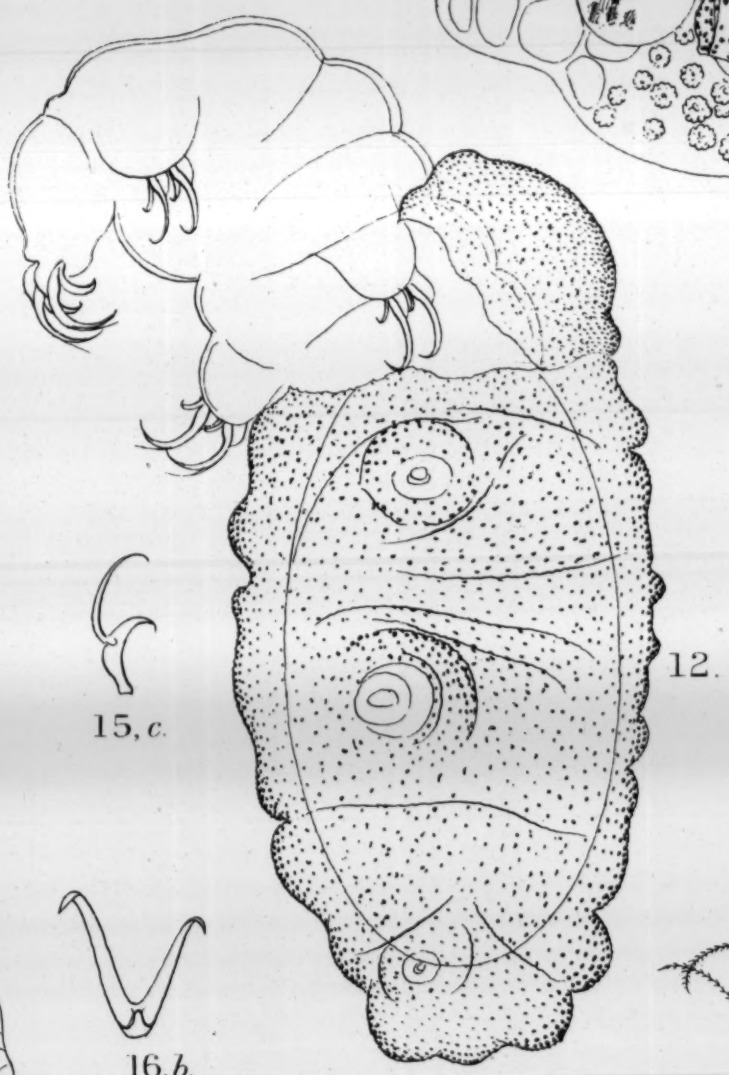
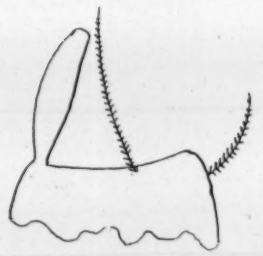


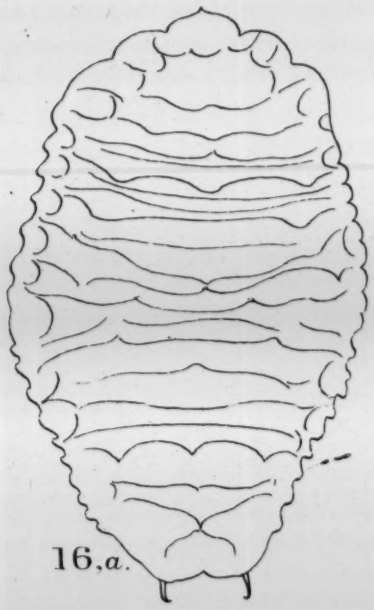
12.

15, *c*.



18, *b*.

16, *b*.



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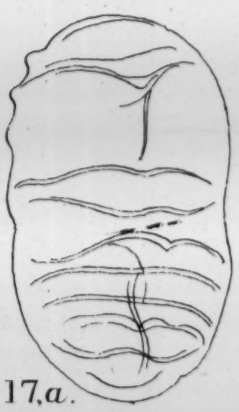

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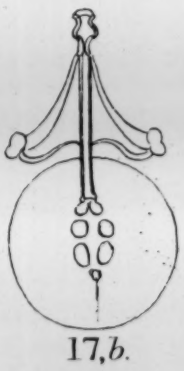
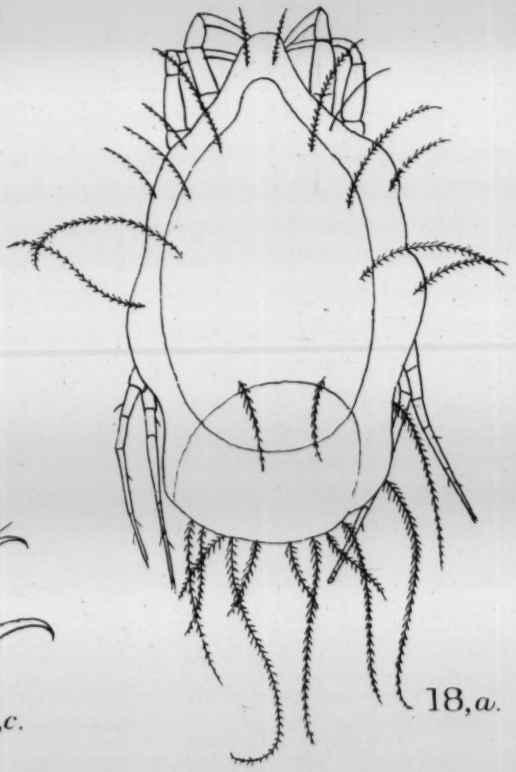


17, *b*.

17, *c*.



18, *a*.

XXXII.—The Boiling and Freezing Points of Concentrated Aqueous Solutions, and the Question of the Hydration of the Solute.

By Rev. S. M. Johnston, B.A., D.Sc., F.R.S.E. (Carnegie Research Fellow, etc.).

(MS. received March 4, 1907. Read same date. Issued separately September 9, 1907.)

PART I.

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In this paper the results of observations of the elevation of the boiling point of aqueous solutions of electrolytes are given, and a few results of observations of the depression of the freezing point, together with conductivity data obtained by observations of conductivity at about 99·4° and 0° Centigrade.

The methods adopted for the boiling-point experiments and the conductivity experiments at 99·4° were the same as those the details of which I have given in the *Trans. Roy. Soc. Edin.*, vol. xlv. (1), p. 193, 1906.

The method adopted in the determination of freezing points was to reduce the temperature of the solution (of which from 20 to 30 cubic centimetres were taken), by the use of a Beckmann freezing-point apparatus or through the use of Dewar vacuum tubes, until some ice was formed in the solution. The tube containing the solution was then withdrawn, placed in a bath of about one degree higher temperature than its freezing point, and the ice allowed to almost disappear. The temperatures of the formation and the disappearance of the ice were noted. When the ice had disappeared the experiment was repeated, the temperature of the freezing bath being kept about one degree below the freezing point of the solution. When ice appeared in the solution, the solution was again removed to the bath of slightly higher temperature than its freezing point, and the ice allowed to disappear. The temperatures of formation and disappearance of ice were noted and their mean taken, which was looked upon as the freezing point of the solution. Had the object of this research been a thorough investigation of dilute solutions from the freezing-point point of view, an effort after greater delicacy of method would have been made. My object, however, was quite different, namely, that a few comparisons might be made of results obtained from the freezing-point method for the more concentrated solutions with those obtained from the boiling-point method, and only a very few determinations of freezing points have been made for the dilute solutions. The freezing mixtures used were, for the Beckmann apparatus, ice and calcium chloride (crystallised) or ice and sodium chloride; for the

vacuum tubes, ether and solid carbon dioxide, or ether, solid carbon dioxide, and liquid air. The solid carbon dioxide was added to the ether, and a freezing temperature obtained approximately as desired. When very low freezing temperatures were desired, of $-70°$ Centigrade or more, the temperature of the ether was reduced to over $-60°$ Centigrade by the use of solid carbonic acid, and the further reduction was effected by means of liquid air blown into a tube inserted in the mixture of ether and carbonic acid. The evaporation of the liquid air quickly produced the degree of cold desired, and there was no difficulty in freezing any of the solutions used. Three Beckmann thermometers and two pentane thermometers were used to give the temperatures of the various freezing solutions. Two of the Beckmann instruments read to one-hundredth of a degree, the third had a range of 12° and read to one-fiftieth of a degree. Two of these instruments were certified correct as to scale reading by the Reichsanstalt. One of the pentane thermometers used had a range of $-65°$ Centigrade and read to one-fifth of a degree, and was made by Goetze; the other had a range of $-100°$ Centigrade, and was made by Hicks. Neither was certified, but they were compared with the standard Beckmann's for the range of temperature of the latter. The readings were taken with the aid of a Beckmann reading glass.

Conductivity experiments at 0° Centigrade were made with the aid of a bath kept at about 0° Centigrade. The cells used were of the Arrhenius and Kohlrausch patterns, and their electrodes, which were of stout platinum foil, were platinised. For measuring resistances, Hartmann and Braun's form of the Kohlrausch bridge was used, with a Bell's telephone and an induction coil by the same makers.* The current was supplied from a two-volt storage cell. The salts used were Messrs Merck & Co.'s "Purest," and water-free salts were used when these were obtainable. From 20 to 30 cubic centimetres of solution were used for an experiment.

The deci-normal solutions of the chlorides, bromides, and iodides were tested volumetrically by a standardised solution of silver nitrate, potassium chromate being used as indicator. The silver nitrate solution was standardised by titration against a tenth normal solution of potassium chloride. The concentration of the acids used was found by volumetric analysis, with the aid of a solution of sodium hydrate, which was standardised by titration against a tenth normal solution of oxalic acid, phenylphthalein being used as indicator. The other salts were analysed gravimetrically.

The following tables contain determinations of elevation per gramme equivalent which have been made from my own observations, and the results are given graphically in fig. 1, p. 859, by curves for which gramme equivalents per litre have been plotted against elevation per gramme equivalent. The curves usually show a minimum point, which occurs at a point corresponding to a concentration of from ·5 to 1 gramme equivalent per litre or thereabout. In a very few instances the curves do not present any minimum point. For higher concentrations than that corresponding to the minimum point, there is for nearly all the salts considered an increase of elevation

* *Wied. Ann.*, 10, 326 (1880).

per gramme equivalent with concentration up to a concentration of about 7 gramme equivalents per litre. When this concentration is reached, further increase of concentration, as indicated by the tables and the curves, results in diminishing the rate of increase of elevation per gramme equivalent with concentration, in the case of some salts the rate becomes negative. That is, a point in concentration may be reached for some salts when further increase of concentration results in a diminution of the elevation per gramme equivalent. This is clearly indicated by the curves for ammonium chloride and barium bromide.

The curves for calcium bromide, calcium chloride, and lithium bromide show a distinct decrease of the rate of increase of elevation per gramme equivalent with concentration for concentrations higher than 7 gramme equivalents per litre. On the other hand, for zinc sulphate an almost stationary value was obtained for elevation per gramme equivalent from a concentration of ·5 gramme equivalents per litre upwards; this is shown by the parallelism of the curve for this salt to the gramme equivalent axis.

Calcium Bromide.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·270	·29
·739	·39
1·570	·43
2·522	·47
3·070	·52
3·696	·57
4·302	·63
4·882	·69
5·562	·76
6·100	·82
6·662	·90
7·041	·96
7·662	·98
8·030	1·04
8·44	1·07

Calcium Chloride.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·530	·69
1·982	·85
2·684	·98
5·320	1·33
7·442	1·60
8·784	1·8
10·981	1·9
12·82	2·0

Strontium Bromide.

Grm. eqs. per Litre.	Elev. per Grm. eq.
1·335	·64
2·232	·73
3·381	·93
4·085	1·16
5·463	1·30

Lithium Chloride.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·250	·92
·922	·80
1·592	1·04
5·31	1·75
7·54	1·85
8·12	2·08
8·48	2·31
9·08	2·40
9·68	2·47
10·34	2·73
12·26	3·12
12·76	3·25
13·14	3·36

Cadmium Chloride.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·330	·39
1·512	·32
2·446	·30
3·182	·32
3·884	·29
4·390	·30
4·936	·30
5·892	·31
6·550	·32

Lithium Iodide.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·201	·84
1·152	·75
1·590	·90
2·250	1·00
2·940	1·07
3·368	1·13
3·88	1·26
4·53	1·28
5·27	1·30
5·96	1·35
6·56	1·39
7·08	1·46
7·44	1·51
8·04	1·59

Barium Bromide.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·421	·750
·620	·753
·950	·77
1·626	·81
2·346	·85
2·962	·88
3·532	1·08
4·090	1·15
5·468	1·19
6·730	1·20
8·076	1·24
8·922	1·25
10·041	1·16

Lithium Bromide.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·262	1·04
·584	·91
1·051	1·03
5·168	1·80
6·178	2·08
6·514	2·17
6·786	2·29
7·048	2·37
7·176	2·46
7·298	2·61
7·98	3·00
8·664	3·16
10·00	3·33
10·56	3·49
11·72	3·57
12·28	3·70

Magnesium Sulphate.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·155	·24
·395	·20
·715	·17
·975	·19
1·320	·21
1·652	·21
1·934	·21
2·210	·20
2·552	·21

Barium Chloride.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·198	·99
·485	·64
1·045	·70
1·885	·69
2·865	·71
3·520	·81
3·855	·87
4·743	·84
5·230	·86
5·812	·78

Zinc Sulphate.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·145	·32
·515	·17
·835	·16
1·025	·16
1·330	·15
1·581	·15
1·855	·16

Cæsium Nitrate.

Grm. eqs. per Litre.	Elev. per Grm. eq.
·312	·99
·758	·89
1·175	·86
1·418	·92
1·725	·92
1·965	·94
2·202	·98
2·378	1·02
2·502	1·05
2·680	1·07

In fig. 2 gramme equivalents per litre have been plotted against equivalent elevation of the boiling point, and molecular depression of the freezing point, and the curves drawn in. The freezing-point * curves show that for nitric and hydrochloric acid a maximum point occurs in the curve, and the boiling-point curve for hydrochloric acid also shows a maximum point.

If the curves for which equivalent elevation has been plotted against concentration for calcium bromide and sulphuric acid be compared, it will be seen that they are almost superimposed, which shows that a salt and an acid may be very much alike in their elevation per gramme equivalent over a wide range of concentration.

* Tables, page 877.

In the diagram on p. 860, fig. 3, curves have been drawn by plotting values of the elevation of the boiling point against the number of grammes of salt added to 100 grammes of water. These show that for some salts elevation increases at a much greater rate per gramme of salt added than for others. The above curves for the very deliquescent salts, viz. calcium chloride, lithium bromide, and lithium chloride, indicate that elevation of boiling point with increase of concentration increases at an increasing rate up to a certain concentration, and falls off very considerably

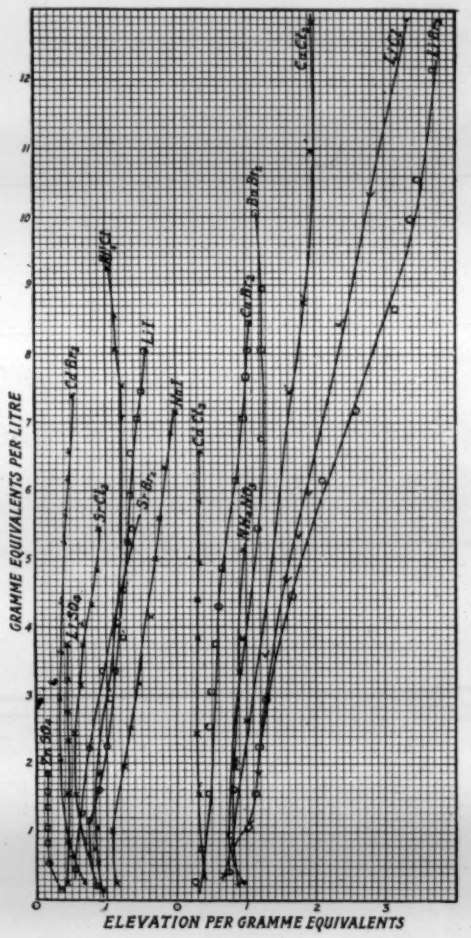

FIG. 1.

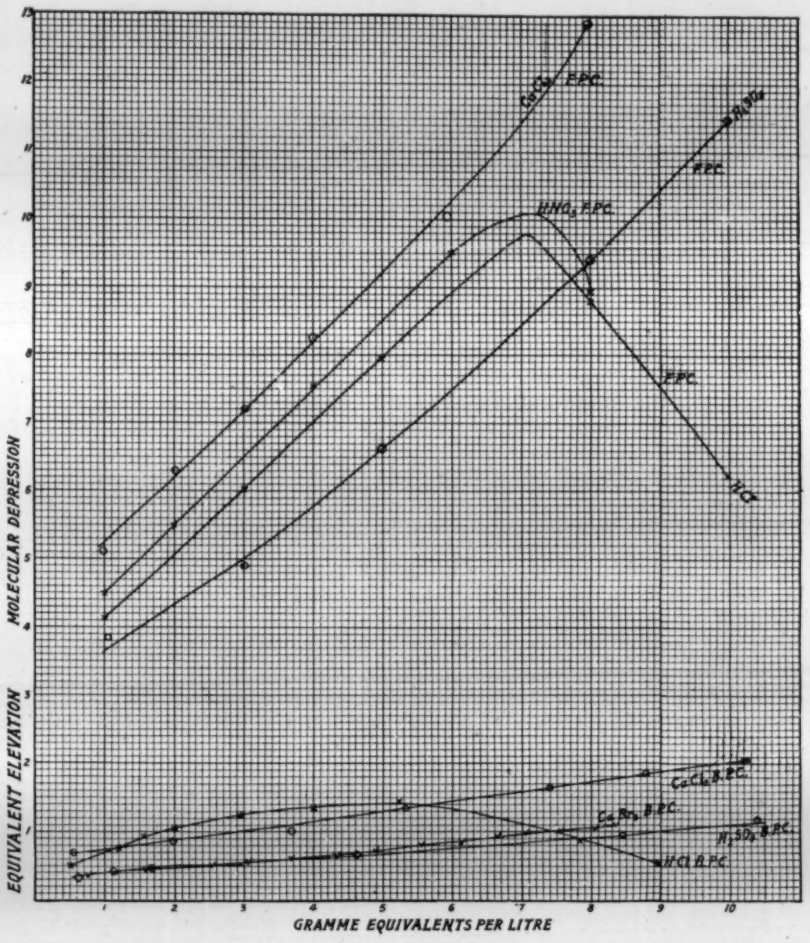

FIG. 2.

after this concentration is reached. For calcium chloride the approximate elevations obtained by successive additions of 10 grammes of salt to 100 grammes of water are 1·58°, 1·90°, 2·74°, 3·08°, 3·80°, 4·42°, 4·4°, 3·04°, 2·30°, and 1·82°, which show that per 10 grammes of salt added there is increase in elevation to a maximum, and decrease after the maximum is reached. The curves for lithium chloride, lithium bromide, lithium iodide, and strontium bromide indicate corresponding increase and decrease. On the other hand, the curves for potassium iodide and lithium sulphate are almost straight lines up to high concentrations; that is, for such salts elevation of the boiling point increases steadily with concentration. Consequently the observations which have been made show a decided difference between salts.

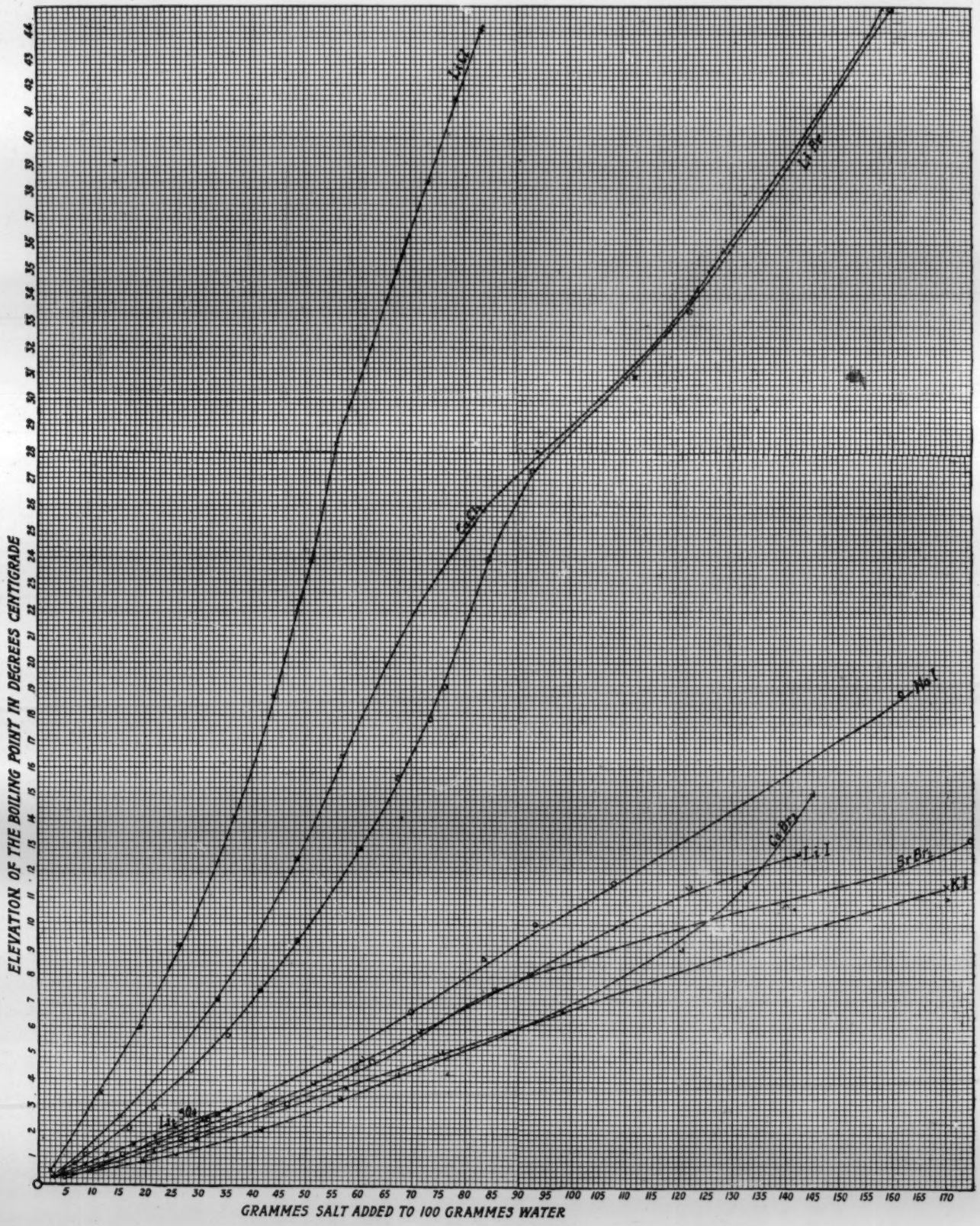
ELEVATION OF THE BOILING POINT IN DEGREES CENTIGRADE
GRAMMES SALT ADDED TO 100 GRAMMES WATER
LiCl
NaCl
KCl
SrBr2
LiBr
LiI
NaBr

FIG. 3.

The curves on p. 860, fig. 3, also show that some salts have a very much larger capacity than others to produce elevation of the boiling point in their solutions. For lithium sulphate an elevation of the boiling point of only from 2 to 3 degrees is obtainable, whilst for lithium chloride more than 40 degrees elevation of boiling temperature may be obtained.

In the following tables conductivity data from my own observations are given for temperatures 99·4° Centigrade and 0° Centigrade over a wide range of concentration.

The results are given graphically by the curves figs. 4, 5, 6. A few values of μ_v/μ_∞ at other temperatures are given, also from my own observations.

At 99·4° Centigrade.

CADMIUM BROMIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
6	169	·053
4	236	·075
2	342	·108
1	462	·146
·5	626	·199
·2	927	·294
·005	3145	1

At 50° Centigrade.

CADMIUM BROMIDE.

Grm. eqs. per Litre.	μ_v/μ_∞
6	·046
4	·073
...	...
1	·177
·5	·250

At 99·4° Centigrade.

LITHIUM IODIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
9	619	·179
7	796	·230
5	998	·289
3	1253	·363
1	1598	·463
·5	1646	·477
·25	1767	·512
·10	1918	·556
·001	3450	1

At 65° Centigrade.

LITHIUM IODIDE.

Grm. eqs. per Litre.	μ_v/μ_∞
7	·214
5	·267
3	·344
...	...
·5	·504
·25	·539
·10	·573

At 99·4° Centigrade.

SODIUM IODIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
8·33	855	·226
7	953	·255
5	1307	·350
3	1745	·467
1	...	·603
·5	2206	·640
·25	2524	·677
·10	2811	·754
·001	3728	1

At 99·4° Centigrade.

CÆSIUM NITRATE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
2	1725	·456
1·5	1990	·526
1	2206	·584
·5	2485	·657
·10	2889	·764
·001	3777	1

At 99·4° Centigrade.

CADMIUM CHLORIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
8	100	·032
4	203	·066
2	345	·113
1	480	·154
·5	635	·207
·25	844	·276
·10	1137	·372
·001	3053	1

At 99·4° Centigrade.

LITHIUM SULPHATE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
5	490	·150
4	584	·178
3	698	·213
2	873	·267
1	1118	·342
·5	1283	·393
·25	1511	·462
·10	1792	·548
·001	3265	1

At 99·4° Centigrade.

AMMONIUM NITRATE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
10	818	·223
8	1005	·275
5	1392	·381
2	1971	·509
1	2198	·601
·5	2387	·645
·25	2484	·679
·10	2744	·751
·100	3653	1

At 50° Centigrade.

AMMONIUM NITRATE.

Grm. eqs. per Litre.	μ_v/μ_∞
10	·214
...	...
5	·381
...	...
...	...
...	...
·25	·741
·10	·802
...	...

At 99·4° Centigrade.

STRONTIUM BROMIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
7	693	·189
5	951	·259
3	1284	·350
1	...	·498
·5	2050	·559
·25	2284	·623
·10	2512	·686
·01	3116	·851
·001	3661	1

At 99·4° Centigrade.

BARIUM CHLORIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
5	859	·235
3	1088	·298
2	1378	·375
1	1742	·478
·5	1940	·533
·25	2240	·611
·125	...	·673

At 99·4° Centigrade.

ALUMINIUM SULPHATE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
4	191	·100
2	234	·122
1	357	·187
·5	419	·214
·25	507	·265
·10	644	·337
·01	1719	·900
·001	1908	1

At 99·4° Centigrade.

BARIUM BROMIDE

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
8	551	·167
4	976	·297
2	1490	·433
1	1615	·491
·5	1955	·595
·25	2003	·610
·10	2253	·686
·001	3283	1

At 99·4° Centigrade.

CALCIUM BROMIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
10	410	·106
8	590	·184
6	769	·201
4	1038	·276
2	1402	·366
1	1501	·393
·5	1685	·440
·25	1858	·486
·10	2028	·530
·01	3116	·816
·001	3821	1

At 0° Centigrade.

HYDROCHLORIC ACID.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
10	457	·186
8	685	·279
5	1088	·443
4	1247	·506
2	1544	·629
1	1890	·771
·01	2442	1
·001	2432	1

At 99·4° Centigrade.

ZINC SULPHATE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
4	218	·120
2	271	·150
1	460	·255
·5	543	·300
·2	657	·364
·02	100	·554
·002	1805	1

At 0° Centigrade.

HYDROBROMIC ACID.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
5	1058	·453
2·5	1525	·653
·5	2147	·915
·01	2261	·969
·001	2334	1

At 0° Centigrade.

LITHIUM CHLORIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
10	738	·100
8	1465	·198
6	1645	·223
3	2308	·313
2	2600	·352
1	3506	·475
·5	3579	·485
·10	4043	·548
·01	4380	·594
·001	7373	1

At 0° Centigrade.

NITRIC ACID.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
10·5	400	·170
5·25	987	·420
2·625	1464	·623
1	1942	·826
·10	2271	·906
·001	2350	1

At 0° Centigrade.

LITHIUM BROMIDE.

Grm. eqs. per Litre.	Eq. Conductivity.	μ_v/μ_∞
6	1911	·266
3	2637	·367
2	2778	·386
1	3730	·519
·01	4332	·603
·001	7182	1

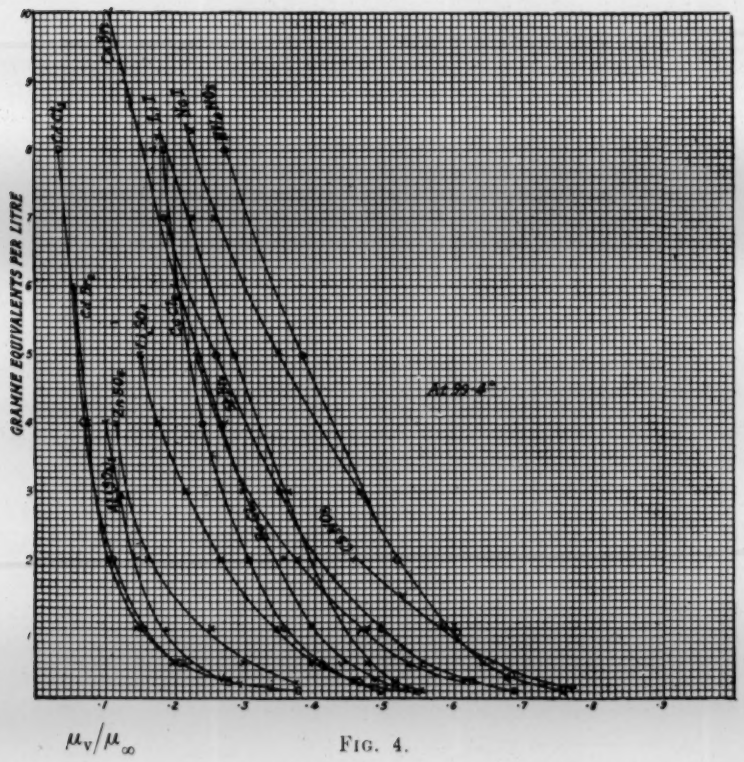

FIG. 4.

Fig. 4, p. 864, shows the general character of the curves for which values of μ_v/μ_∞ at 99·4° are plotted against gramme equivalents per litre. These show that the ratio of concentration to μ_v/μ_∞ varies very considerably for different salts even to the highest concentrations. The difference in these values are in general less divergent the higher the concentration. In fig. 5 values of μ_v/μ_∞ at 0° and at 99·4° Centigrade have been plotted against concentration. The 0° point curves have been marked with zeros, the 99·4° Centigrade curves with 99·4. On comparison, it is seen that the zero curves, speaking generally, lie more to the right of the diagram than the 99·4° curves,

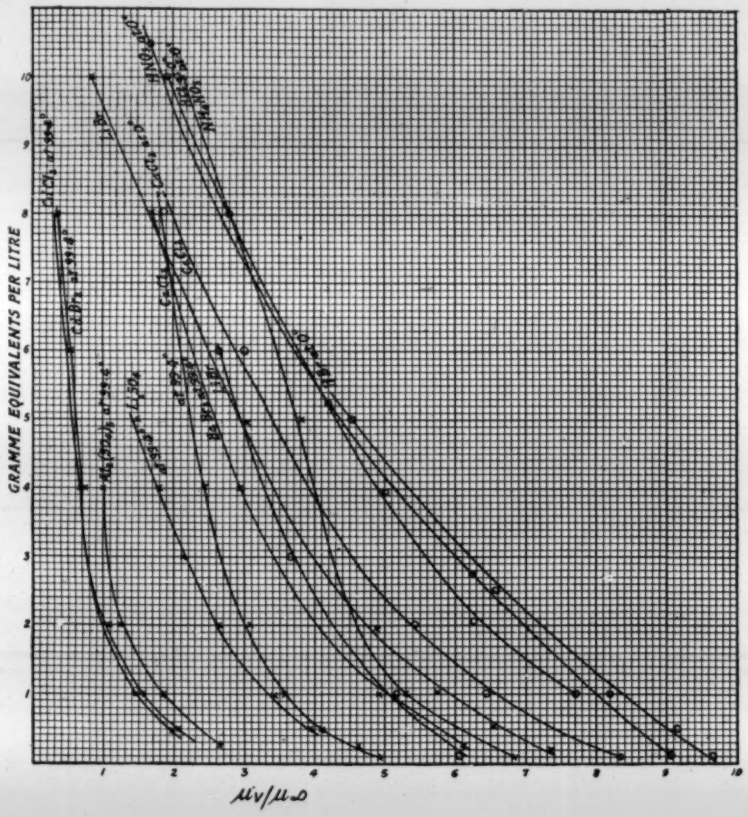

Fig. 5.

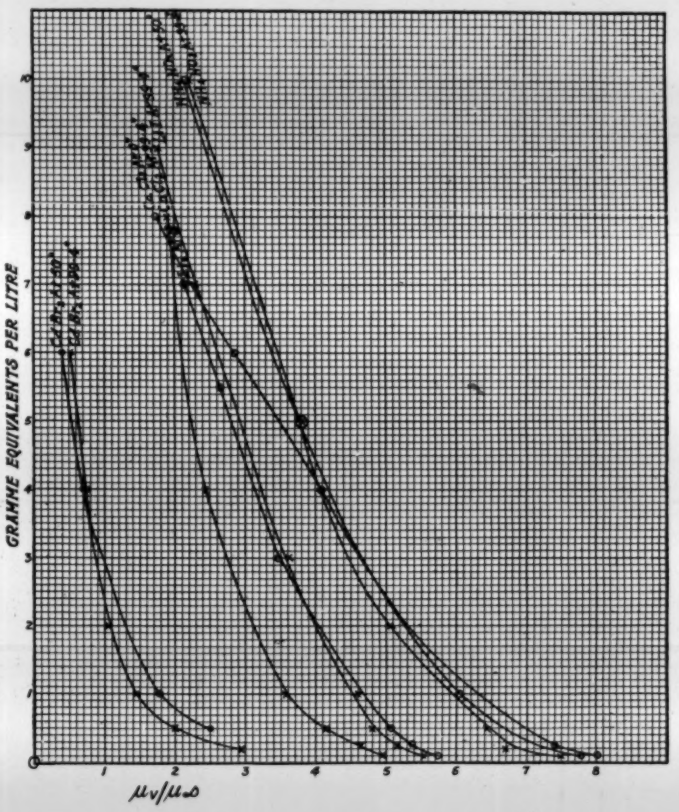

Fig. 6.

which indicates a greater degree of ionization at the lower than at the higher temperature. It is evident that the zero curves are at the higher concentrations inclined at a smaller angle to the axis of μ_v/μ_∞, and that consequently the curves for the two temperatures approach each other at the high concentrations, and may even cross each other. In fig. 6, the relations between curves at 99·4° Centigrade and at other temperatures are shown. From these it appears that for the dilute solutions the ionization is greater for the lower temperature at the same concentration, but that for the concentrated solutions the ionization, or rather the value of μ_v/μ_∞, is greater at the higher temperature. It would seem also that, the nearer the temperature of the observations for the isothermals for which the comparison is made, the lower is the concentration at which their point of intersection lies.

JONES and WEST have given some conductivity values for acids for which I have also obtained data; consequently, it is possible to compare their results with mine. It may be noted that the differences between the values obtained, which are not large, are covered by the errors which have resulted from the volumetric analysis of the acids supplied made to obtain their concentration, the errors attaching to making up and diluting solutions perhaps several times, the error of temperature or of the experimental observation of conductivity, and difference in the purity of the water * used.

NITRIC ACID. Mine.		NITRIC ACID. JONES and WEST.		POTASSIUM NITRATE.			
Litres per Grm. eq.	Conductivity.	Litres per Grm. eq.	Conductivity.	Litres per Grm. eq.	Conductivity. KOHLRAUSCH.	Conductivity. KRANNHALS.	Conductivity. JONES and WEST.
·095	40·0	...	...	2	83·9	83·3	83·1
...	...	...	...	8	...	96·6	95·6
·190	98·7	...	...	10	103·7	...	...
...	...	...	...	...	...	...	...
·380	146·4	...	...	16	...	101·4	100·3
...	...	...	...	20	106·7	...	..
1	194·2	...	...	32	...	105·7	104·3
...	...	...	...	100	114	...	...
...	...	...	...	128	...	112·7	109·3
...	...	4	222·4	...	...	...	...
10	227·1	8	226·9	...	...	...	...
...	...	16	231·3	...	...	...	...
...	...	32	235·4	...	...	...	...
...	...	128	238·3	...	...	...	...
1000	235·0	1024	231·4	...	...	...	...

The following tables contain the results of computations showing the amount and character of the hydration which, according to the hydration theory, must be assumed in order to account for the variation with concentration of the so-called boiling point constant.

These computations assume (1) that the ionization coefficients can be determined with sufficient accuracy from observations of electrical conductivity; and (2) that the elevation produced in the boiling point (or depression of the freezing point, as the case may be) by each gramme molecule or gramme ion (hydrated or unhydrated) in a given quantity of water to which salt has been added is independent of the concentration of the solution thus formed.

I am quite aware of the doubtfulness of these assumptions, but it may be pointed out with regard to the first that in the computation formulæ which are given below the factors involving the ionization coefficients α are $1+\alpha$, $1+2\alpha$, etc., and that, consequently, the percentage error of the result, due to errors in the coefficients, is much less than the percentage errors themselves; and, with regard to the second, it should be noted that through considerable concentration ranges the diminution of vapour pressure has been found to be at any rate roughly proportional to concentration.

* *Trans. Roy. Soc. Edin.*, 45, 211, 1906.

The hope was consequently entertained that notwithstanding the doubtful nature of the above assumptions, the computations referred to might throw some light on the constitution of concentrated solutions, and afford additional evidence, either in confirmation of, or in opposition to, the hydration theory.

The hydration calculations were made from the following formulæ :—

$$C = \frac{m\mathrm{W}\Delta\mathrm{E}}{(1 + n - 1^{\alpha})\Delta w}$$

$$C' = \frac{m\mathrm{W}'\Delta\mathrm{E}}{(1 + n - 1^{\alpha})\Delta w}$$

From which $$\mathrm{W} - \mathrm{W}' = \frac{\mathrm{W}(\mathrm{C} - \mathrm{C}')}{\mathrm{C}}.$$

The number of molecules of water of hydration per molecule or ion of salt in solution, on the assumption that both ions and molecules hydrate,

$$= \frac{(\mathrm{W} - \mathrm{W}')m}{18w(1 + n - 1^{\alpha})};$$

the number per ion, if ions only hydrate,

$$= \frac{(\mathrm{W} - \mathrm{W}')m}{18n\alpha w};$$

the number per molecule, if molecules only hydrate,

$$= \frac{(\mathrm{W} - \mathrm{W}')m}{18(1 - \alpha)w}.$$

In the above formulæ C is the observed elevation of the boiling-point constant, and C′ the theoretical value of the constant.

m = molecular weight of salt.
W = weight of water used in an experiment in grammes.
W′ = ,, ,, acting as solvent, in grammes.
ΔE = increment of elevation due to Δw grammes of salt added to the solvent or a solution.
Δw = increment of salt added to solvent or solution.
n = number of ions into which a molecule of salt dissociates.
$\alpha = \mu_v/\mu_\infty$ assumed to be the ionization coefficient, where μ_v is the equivalent conductivity at the concentration 1/v, and μ_∞ the equivalent conductivity at infinite dilution, each at 99·4° Centigrade.

Freezing-point calculations were made by the use of the formula

$$\mathrm{K} = \frac{m.w.\Delta}{\mathrm{W}(1 + n - 1^{\alpha})} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

when K is the value of the depression constant, and Δ the observed depression. The other symbols have the same meaning as given above.

From (1) the various expressions for calculating the amount of hydration may easily be deduced; and they correspond with those already given above in the case of the boiling point for the calculation of boiling-point hydration data. When

calculations were made from boiling-point data, a correction for error in the determination of the boiling point of water was made according to the method explained *Trans. Roy. Soc. Edin.*, xlv., 203, 1906.*

SODIUM BROMIDE.

Grms. Salt to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
12·2385	1·14	·542	1·050	579	10·8	3·4	4·9	11
19·8305	1·90	·502	1·722	615	16·0	3·2	4·8	10
24·045	2·05	·478	2·182	636	18·8	3·1	4·8	8·7
96·547	5·21	·336	10·300	833	41·2	1·8	3·7	3·7
100·989	5·34	·328	11·240	873	40·8	1·8	3·6	3·5
104·566	5·43	·324	11·902	897	42·0	1·7	3·5	3·5
109·400	5·55	·320	12·845	928	44·0	1·7	3·7	3·4
111·248	5·61	·316	13·100	934	44·4	1·7	3·7	3·3

SODIUM CHLORIDE.

Grms. Salt to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
·6217	·141	·854	·097	501	...	...	...	...
8·4132	1·38	·612	1·322	578	13·6	3·3	4·3	13·4
9·3225	1·52	·602	1·482	581	14·0	3·1	4·2	13·5
9·6136	1·58	·596	1·619	595	15·2	3·2	4·3	12
11·366	1·84	·572	1·842	610	16·4	3·0	4·2	11·0
11·776	1·96	·562	1·971	624	17·6	3·1	4·4	11·6
12·843	2·08	·552	2·132	632	18·8	3·2	4·4	11·3
13·860	2·26	·538	2·213	637	20·8	3·2	4·6	11·0
15·088	2·44	·522	2·551	656	22·0	3·2	4·6	10·1
15·704	2·52	·516	2·689	666	23·2	3·1	4·8	10·0
16·353	2·62	·508	2·818	672	24·0	3·2	4·9	9·6
16·911	2·70	·502	2·936	684	26·0	3·4	5·1	10

* Corrections for error in determining boiling point of water :—

For calcium chloride	·000	For strontium bromide	·000
„ „ bromide	+·010	„ magnesium sulphate	·000
„ lithium bromide	−·064	„ zinc sulphate	−·020
„ „ sulphate	+·014	„ ammonium iodide	·000
„ sodium iodide	−·020	„ „ chloride	+·015
„ lithium iodide	−·010	„ lithium nitrate	·000
„ barium chloride	−·080	„ ammonium nitrate	+·020
„ „ bromide	−·060	„ cadmium bromide	−·120
„ potassium iodide	·000	„ „ chloride	−·023
„ lithium chloride	·000	„ cæsium nitrate	−·039

BARIUM CHLORIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
2·0725	·198	631	·197	542	...	...	..	...
4·0065	·485	565	·313	569	8·8	11·0	16	60
11·1601	1·045	473	·738	638	19·0	10·3	12·9	38·7
19·9165	1·885	376	1·308	756	25·8	8·7	14·0	26·4
31 7879	2·865	317	2·058	823	37·4	8·4	14·4	20·3
41·1498	3·520	292	2·854	949	45·5	7·7	14·3	18·4
49·6821	3·855	285	3·413	967	46·2	6·8	14·5	15·0
60·3486	4·743	258	4·134	1027	49·6	6·3	12·3	13·0
69·9568	5·230	242	4·528	1002	48·3	5·4	11·1	10·8
80·9390	5·812	224	4·548	895	42·1	4·1	9·0	7·8

SODIUM IODIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
4·48	·250	·670	·281	509	...	...	...	..
15·47	1·002	·600	1·082	620	16·0	5·5	6·6	22
31·63	1·970	·534	2·427	728	28·5	5·2	7·0	16·6
41·3	2·516	·488	3·412	805	34·3	4·7	7·2	14·4
54·57	3·208	·452	4·794	884	42·8	4·4	7·2	12·0
70·58	4·146	·398	6·696	991	47·6	3·9	7·1	9·4
83·19	5·008	·350	8·314	1084	52·3	3·8	7·3	7·9
93·37	5·608	·322	10·014	1203	56·4	3·7	7·1	7·3
102·94	6·344	·286	11·610	1277	59·0	3·6	8·4	7·3
114·22	6·84	·264	13·334	1343	61·9	3·5	8·5	6·0
120·8	7·14	·244	14·359	1399	63·2	3·4	8·9	5·6
136·0684	7·34	·245	16·244	1435	64·0	3·1	8·0	5·1
142·4532	7·44	·242	17·224	1456	64·6	3·0	7·8	5·0
147·2672	7·66	·240	18·172	1466	64·6	3·0	7·6	4·7
151·9813	7·72	·236	18·594	1481	65·3	2·8	7·6	4·6

BARIUM BROMIDE.

Grms. Salt added to 100 Grms. Water.	Grms. eqs. per Litre.	Ionization Co eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
6·05	·421	·581	·315	567	8·1	11	13·2	66
9·28	·620	·549	·466	614	15·9	14·4	18·8	65
15·16	·950	·498	·735	710	20·5	14·0	18·2	55
26·48	1·626	·449	1·323	740	30·2	10·2	15·0	34·4
37·98	2·346	·401	2·000	834	39·4	8·5	12·3	29·2
48·18	2·962	·361	2·619	896	43·5	8·6	13·5	23·5
57·47	3·532	·324	3·82	1072	51·9	9·1	15·1	16·8
66·33	4·090	·282	4·71	1288	60·7	9·6	14·4	20·3
87·99	5·468	·247	6·53	1456	64·2	8·5	16·3	16·3
108·2	6·730	·204	8·14	1556	66·6	7·7	16·8	12·9
130·4	8·076	·174	10·02	1677	69·1	6·5	16·9	10·6
144·1	8·922	·146	11·13	1786	71·4	6·4	18·9	9·2
164·7	10·041	·125	11·61	1648	69·0	5·5	18·0	8·6

LITHIUM SULPHATE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
4·7886	·858	·355	·401	559	7·4	5·5	8	15
8·6387	1·585	·296	·700	570	11·5	5·2	10·4	11·7
12·9554	2·329	·240	1·049	614	15·6	5·0	10·4	10·5
17·8051	3·262	·201	1·461	650	20·9	5·0	11·8	8·7
21·8320	3·768	·178	1·787	669	22·4	4·7	12·2	7·6
25·8236	4·345	·161	2·136	692	25·1	4·5	12·8	7·0
30·6516	4·974	·150	2·540	706	26·5	3·8	11·3	6·0
33·8436	5·362	·143	2·777	704	26·5	3·5	10·8	5·4
36·1709	5·655	·138	2·832	678	23·8	3·1	9·7	4·7

Ammonium Bromide.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
80·4304	6·22	·344	7·66	700	25·9	1·3	2·5	2·1
102·9452	7·32	·295	10·36	769	32·6	1·2	2·7	2·4
130·7117	8·28	·236	11·76	780	33·3	1·1	2·9	1·8
145·2262	8·90	·212	14·78	822	36·7	1·1	3·2	1·7
178·1328	9·52	·178	15·66	731	29·2	·8	2·4	1·1

Ammonium Chloride.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
52·6524	7·082	·307	8·890	697	25·1	1·1	2·3	2·0
57·0751	7·524	·284	9·292	673	23·1	·9	2·0	1·7
62·5668	8·082	·248	9·517	650	20·4	·7	1·9	1·3
68·4148	8·562	·218	9·812	628	17·7	·6	1·7	·9
75·9968	9·261	·179	9·952	600	14·8	·4	1·6	·7

Magnesium Sulphate.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.
1·040	·155	·343	·038	351
2·4835	·395	·296	·082	294
4·5438	·715	·262	·138	305
6·3796	·975	·235	·190	296
8·5292	1·320	·212	·275	348
10·7809	1·652	·184	·352	371
12·9683	1·934	·170	·406	369
15·1495	2·210	·155	·440	360
18·3368	2·552	·130	·544	356

Zinc Sulphate.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.
1·1943	·145	·431	·074	274
4·3468	·515	·282	·091	216
7·0880	·835	·261	·135	226
8·9548	1·025	·242	·167	215
11·4894	1·330	·207	·192	219
12·288	1·581	·186	·242	245
16·3508	1·855	·159	·297	259

STRONTIUM BROMIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the Assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
16·8653	1·335	·481	·857	640	19·0	8·1	11·0	31
25·7504	2·232	·405	1·645	781	33·9	7·2	13·9	27·2
46·9540	3·381	·355	3·152	971	46·2	7·9	13·2	20·0
62·4580	4·085	·299	4·770	1190	55·7	7·7	13·3	15·1
84·2166	5·463	·242	7·526	1489	65·2	7·9	15·2	14·0
168·7964	...	...	13·32	1955	73·4	...	...	6·0
207·2164	...	...	19·94	2373	78·2	...	...	5·1
238·4624	...	...	25·03	2598	80·2	...	...	4·6
262·5140	..	...	27·81	2620	82·9	...	...	4·3
288·1976	...	...	31·12	2674	83·6	...	...	4·0

LITHIUM CHLORIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the Assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
2·7200	·441	·632	·587	555	6·8	3·6	5	18·3
6·9101	1·582	·534	1·592	633	8·3	3·1	6	13
10·3496	2·231	·462	2·547	710	27·2	4·2	6	11
13·1906	2·870	·426	3·438	775	33·3	4·0	7	10
16·6108	3·603	·384	4·649	856	39·9	4·0	7	9
19·7689	4·251	·344	6·017	959	46·2	4·1	7	8
23·2570	4·704	·322	7·542	1009	49·7	4·0	7	7
26·8559	5·312	·294	9·294	1133	54·4	3·6	8	6
30·8679	5·981	·264	1·419	1243	58·5	3·5	8	6
29·4576	6·082	·268	9·523	1083	52·3	3·4	7·9	6
37·3714	7·54	·208	14·013	1321	61·2	3·2	9·8	4·8
41·1427	8·12	·188	16·919	1501	63·9	3·0	9·8	4·5
44·4040	8·48	·178	18·760	1594	65·3	2·9	9·6	4·3
47·5705	9·08	·166	21·860	1670	66·6	2·8	10·0	3·9
51·3536	9·68	·152	23·956	1720	68·0	2·7	10·0	3·5
56·9486	10·34	·142	28·24	1843	72·1	2·6	10·6	3·4
73·4651	12·26	·100	38·272	2012	74·1	2·3	12·1	2·7
78·1483	12·76	·096	41·564	2059	74·8	2·4	11·9	2·4
83 2811	13·14	·088	44·168	2069	74·8	2·3	13·0	1·9

CALCIUM CHLORIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the Assumption that		
						Molecules and Ions Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
2·9512	·530	·404	·367	759	29·9	37·3	65	130
12·1869	1·982	·308	1·694	954	44·5	18·9	24·8	33·8
15·1123	2·684	·283	2·649	1150	55·1	14·5	26·4	32·1
33·6344	5·320	·227	7·121	1616	68·0	8·3	17·7	15·7
48·8215	7·442	·203	12·483	2016	74·1	6·8	15·6	10·9
57·2138	8·784	·158	16·40	2107	78·9	6·5	18·4	10·3
70·4276	10·981	·044	21·4	3262	84·3	...	...	7·4
83·5696	12·82	...	25·8	3420	85·0	...	...	6·2
102·4066	...	...	30·8	3348	85·0	...	...	5·4
118·8300	...	...	35·9	3365	85·0	...	...	4·4
148·7988	...	...	44·8	3579	85·0	...	...	3·2
156·0628	...	...	47·8	3381	85·0	...	...	3·2
164·5028	...	...	49·8	3382	85·0	...	...	2·2
176·1308	...	...	53·0	3456	85·0	...	...	1·9

CALCIUM BROMIDE.

Grms. Salt added to 100 grms. Water.	Grm. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
2·4860	·270	·456	·079	500	...	...	...	...
7·2841	·739	·427	·296	587	11·5	10·4	15·6	31·3
16·2329	1·570	·370	·679	621	16·3	6·6	11·2	19·0
25·1627	2·522	·332	1·176	707	26·5	7·2	12·0	18·0
33·3213	3·070	·310	1·616	744	30·6	6·4	11·3	15·6
41·3336	3·696	·284	2·116	801	35·3	6·1	12·5	13·7
49·5856	4·302	·259	2·723	875	40·8	6·0	12·0	12·4
56·8598	4·882	·241	3·413	965	46·2	6·0	12·5	11·7
67·0970	5·562	·216	4·233	1041	50·3	5·8	13·2	10·7
75·5425	6·100	·198	5·023	1112	53·7	5·6	13·6	9·9
82·9283	6·662	·181	6·018	1217	57·9	5·6	14·3	9·4
91·2274	7·041	·178	6·787	1265	59·1	5·3	13·8	8·7
98·3837	7·662	·162	7·563	1527	60·8	5·2	14·7	8·3
105·1987	8·030	·154	8·387	1388	62·5	5·1	14·5	7·8
111·4316	8·421	·143	9·107	1413	63·9	5·0	14·8	7·5
122·1783	...	·163	11·545	1541	66·6	4·6	12·6	7·1
125·7878	...	·143	15·107	1728	70·0	4·5	13·6	6·7
236·9718	...	·008	38·4	3244	84·3	...	...	3·9
256·8504	...	...	40·4	3235	84·3	...	...	3·7
261·0398	...	...	42·4	3254	84·3	...	...	3·5
272·522	...	...	44·0	3231	84·3	...	...	3·4
283·8660	...	...	45·4	3200	84·3	...	...	3·3

LITHIUM IODIDE.

Grms. Salt added to 100 grms. Water.	Grms. eqs. per Litre.	Ionization Co-eff.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
2·6492	·201	·532	·170	524	....	...	...	...
13·5020	1·152	·449	·872	585	7·5	2·9	4·7	8·7
22·3869	1·590	·432	1·481	609	14·9	3·4	5·8	8·7
33·3240	2·250	·408	2·272	644	19·7	3·1	5·5	7·6
43·9892	2·940	·372	3·182	699	25·8	3·2	5·8	7·3
51·3903	3·368	·346	3·846	742	29·9	3·2	6·2	6·7
61·5209	3·88	·322	4·866	792	34·6	3·1	6·5	6·2
71·6502	4·53	·306	5·826	833	38·0	3·0	6·5	5·7
81·5456	5·27	·278	6·840	875	40·8	2·9	6·7	5·2
92·1291	5·96	·256	8·042	920	43·5	2·8	6·7	4·7
102·7276	6·56	·242	9·218	971	46·9	2·7	7·0	4·5
112·8092	7·08	·226	10·409	1004	48·3	2·6	7·2	4·2
120·3844	7·44	·216	11·250	1026	49·6	2·8	7·1	3·8
132·9223	8·04	·204	12·730	1063	51·7	2·5	7·2	3·6

LITHIUM BROMIDE.

Grms. Salt added to 100 Grms. Water.	Grm. eqs. per Litre.	Ionization Co-effi.	Elevation of Boiling Point.	Elevation Constant.	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions. Hydrate; per Mol. and Ion.	Ions only Hydrate; per Ion.	Molecules only Hydrate; per Mol.
4·3193	·584	·654	·532	562	7·5	5·0	6·2	30
6·6300	·764	·608	·791	595	12·9	5·8	7·3	26
8·9964	1·051	·564	1·085	630	17·7	6·2	8·4	24
10·9534	1·260	·548	1·428	665	21·0	6·1	8·6	21
14·1834	1·549	·526	1·798	698	25·1	5·9	8·4	19
16·9496	1·731	·492	2·199	736	29·9	5·8	8·7	17
19·8505	2·243	·476	2·695	782	32·0	5·6	8·9	15
22·5256	2·732	·448	3·171	859	37·4	5·5	9·0	14
25·6332	2·945	·434	3·741	874	40·8	5·3	9·0	13
28·6892	3·286	·416	4·359	920	43·3	5·2	9·0	12
35·2063	3·94	·376	5·765	1026	49·9	5·0	9·0	10
41·8825	4·48	·344	7·421	1136	54	5·2	9·1	9·8
48·8539	5·168	·308	9·393	1269	59·1	4·5	9·6	8·3
60·2576	6·178	·268	12·867	1469	64·6	4·1	9·7	7·1
63·9893	6·514	·252	14·173	1539	66·6	4·0	10·0	6·8
67·6294	6·786	·244	15·597	1605	68·0	3·9	9·9	6·6
70·5799	7·048	·234	16·754	1671	69·4	3·8	10·1	6·2
73·3475	7·176	·231	17·897	1725	70·0	3·7	10·0	6·0
81·4939	7·298	·228	19·092	1772	70·7	3·5	9·9	6·0
84·7320	7·98	·208	23·992	1963	72·1	3·3	9·9	5·4
93·2212	8·664	·191	27·392	2059	73·8	3·3	9·7	4·7
112·0327	10·00	·151	33·392	2179	74·1	2·9	9·7	3·8
120·4144	10·56	·135	36·892	2280	76·1	2·6	11·5	3·5
139·5604	11·72	·105	41·792	2310	76·8	1·8	13·0	2·6
149·4177	12·28	·091	45·392	2320	77·6	1·9	13·5	2·3

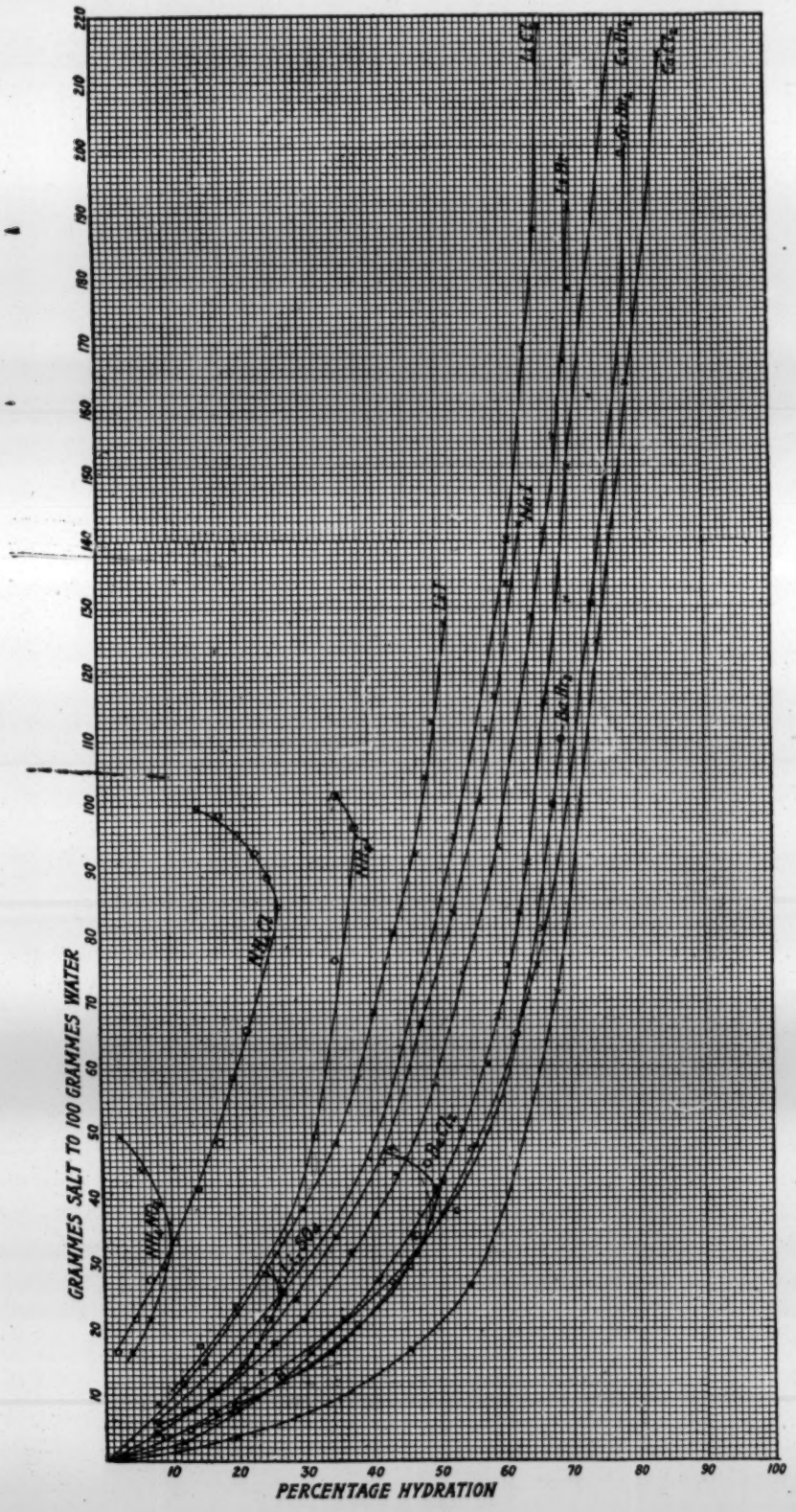
GRAMMES SALT TO 100 GRAMMES WATER
PERCENTAGE HYDRATION
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220

FIG. 7.

The following tables contain the results of the freezing-point observations which have been made. The observations have extended, for a few salts and acids, over a wide range of concentration, and were made for the sake of comparison with results obtained at the boiling point. The results are given graphically in the comparative sets of curves figs. 8 and 10 (pages 878 and 880).

AMMONIUM NITRATE.

Grms. Salt per 100 Grms. of Water.	Grm. eqs. per Litre.	Depression of the Freezing Point.	Equ. Depression.	μ_v/μ_∞	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions. only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
...	8	8·65	1·08	·298	0	...	...	...
64·32	6	14·8	2·60	·391	3·3	...	...	...
38·88	4	11·264	2·816	·465	3·3	...	...	...
17·58	2	6·565	3·282	·512	14·3	2·7	3·9	8·3
8·10	1	3·168	3·168	·543	10·1	3·7	5·1	13·7
3·78	·5	1·54	3·08	·584	4·4	3·3	4·4	12·8

LITHIUM CHLORIDE.

Grms. Salt per 100 Grms. of Water.	Grm. eqs. per Litre.	Depression of the Freezing Point.	Equ. Depression.	μ_v/μ_∞	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions. only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
53·448	10	73·0	7·30	·100	77·1	3·2	17·1	3·8
43·520	8	62·0	7·77	·198	73·4	3·4	10·2	5·0
29·104	6	45·5	7·58	·223	70·0	4·6	11·2	7·3
14·824	3	12·95	4·22	·313	43·5	5·6	12·0	11·0
10·064	2	7·90	3·95	·352	36·4	6·5	12·6	13·4
5·236	1	3·10	3·1	·475	22·8	7·0	11·4	21·0
2·652	·5	1·50	3·0	·485	17·0	8·9	12·9	176·0

Calcium Chloride.

Grms. Salt per 100 Grms. of Water.	Grm. eqs. per Litre.	Depression of the Freezing Point.	Equ. Depression.	μ_v/μ_∞	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
51·9	8	52·8	6·60	·131	82·3	7·9	26·0	11·7
37·8	6	30·00	5·00	·211	73·6	8·4	18·9	15·2
24·7	4	16·60	4·15	·304	64·2	8·3	17·5	24·5
12·1	2	6·32	3·16	·377	48·6	14·1	21·9	40·3
5·8	1	2·58	2·58	·449	39·5	22·1	31·2	81·1
2·8	·5	1·16	2·33	·577	33·3	34·2	42·5	185·0
·48	·10	·280	2·80	·679	21·6	120	133	1200

Nitric Acid.

Grms. Salt per 100 Grms. of Water.	Grm. eqs. per Litre.	Depression of the Freezing Point.	Equ. Depression.	μ_v/μ_∞	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions. only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
98·8	10·5	52·0	4·94	·158	67·1	2·0	7·6	2·7
66·8	8	71·5	8·94	·271	73·6	3·0	7·2	5·2
41·3	6	57·85	9·641	·343	75·6	4·7	9·6	9·7
21·4	4	30·28	7·57	·463	62·1	6·9	11·1	19·1
11·8	2	11·0	5·50	·620	...	...	...	...
6·48	1	4·50	4·50	·767	...	...	...	...
3·18	·5	1·86	3·72	·828	...	...	...	...
1·45	·15	·980	3·92	·865	...	...	...	...

Hydrochloric Acid.

Grms. Salt per 100 Grms. of Water.	Grm. eqs. per Litre.	Depression of the Freezing Point.	Equ. Depression.	μ_v/μ_∞	Per cent. Hydrate.	Molecules of Water of Hydration, on the assumption that		
						Molecules and Ions Hydrate ; per Mol. and Ion.	Ions only Hydrate ; per Ion.	Molecules only Hydrate ; per Mol.
44·93	10	62·5	6·25	·186	64·5	2·4	7·4	3·4
31·68	8	70·5	8·81	·279	73·2	3·6	8·2	6·3
28·8	7	74·0	10·571	·332	76·6	3·9	8·1	8·1
25·0	5	39·9	7·98	·443	66·3	4·2	6·8	10·9
12·2	3	18·06	6·02	·568	51·6	5·3	7·3	20·4
3·72	1	4·118	4·118	·771	20·0	6·1	6·9	46·2

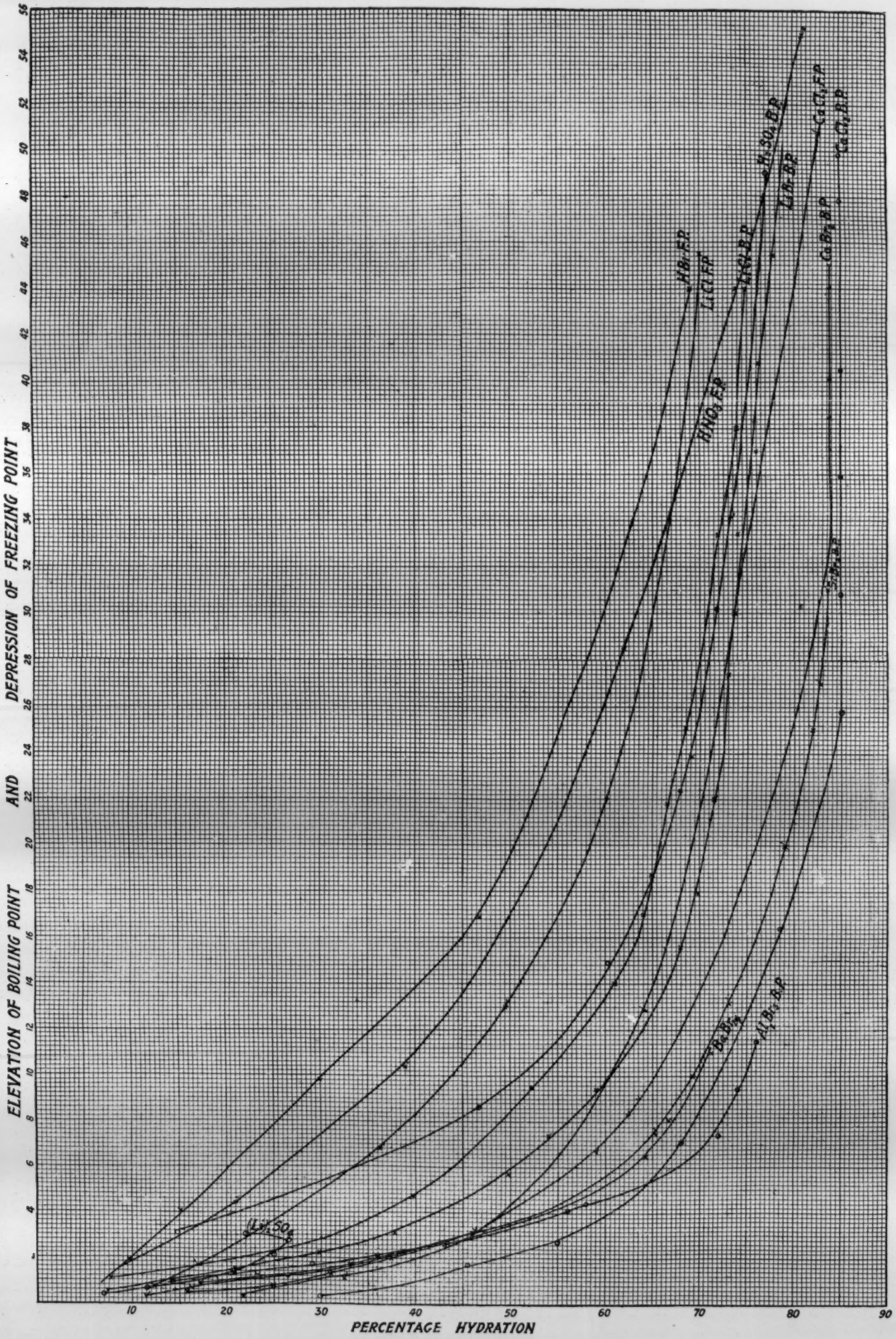
ELEVATION OF BOILING POINT AND DEPRESSION OF FREEZING POINT
PERCENTAGE HYDRATION
HBr, F.P.
LiCl, F.P.
HNO3, F.P.
LiBr, B.P.
H2SO4, B.P.
LiBr, B.P.
CaCl2, F.P.
CaCl2, B.P.
CaBr2, B.P.
SrBr2, B.P.
BaBr2
Al2Ba3, B.P.
Li2SO4

FIG. 8.

The curves for which values of percentage hydration have been plotted against grammes of salt added to one hundred grammes of water (fig. 7, p. 875) show how hydration varies with concentration and the limit toward which it approaches at high concentrations. The curves also show the difference in hydration capacity of the several salts. It may be pointed out that some of the curves have a well-defined maximum point, which corresponds to a certain concentration which varies with the salt (Li_2SO_4, $BaCl_2$, NH_4Cl, and NH_4NO_3). For higher concentrations than that represented by the maximum point the amount of hydration falls off. It almost vanishes at the highest concentration for ammonium nitrate.

The diagram shows that for other salts (*i.e.* $CaCl_2$, $CaBr_2$, $SrBr_2$, LiBr, and LiCl)

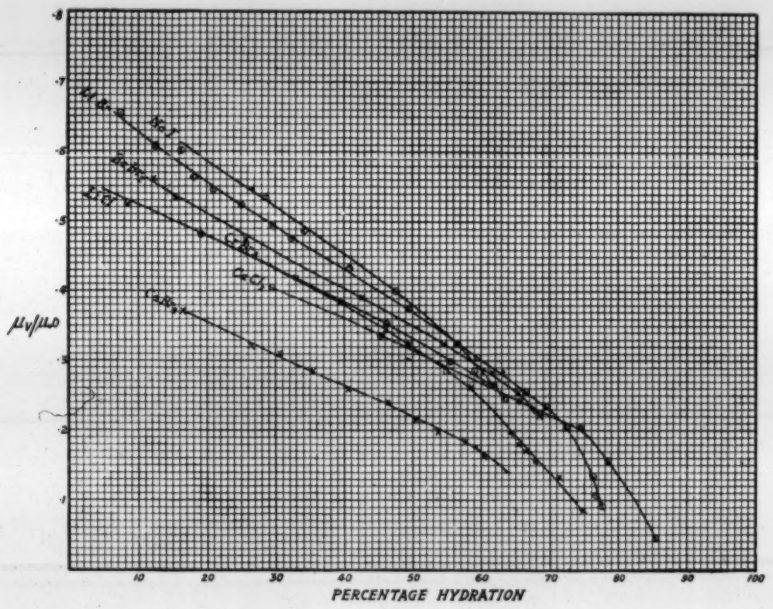

FIG. 9.

hydration increases up to the highest concentrations observed, and the curves do not contain a maximum point.

In fig. 8 elevation of the boiling point and depression of the freezing point have been plotted against percentage hydration. The curves show that the percentage hydration per degree of elevation is greater for the dilute solutions than the percentage hydration per degree of depression, but that with increase of concentration this difference diminishes, until for high concentrations, for the salts and acids considered, the degree of hydration is much the same per degree of depression of freezing point and per degree of elevation of the boiling point. The diagram indicates further that at high concentrations the percentage hydration is approximately the same whether viewed from the freezing point, or elevation of the boiling point, point of view. This is also indicated by the curves on p. 880, fig. 10.

The curves,* fig. 9, show the relation between values of μ_v/μ_∞ and percentage hydration, and indicate the maximum point to which hydration tends for several salts at the

* The straightness of several such curves I have already pointed out, *Trans. Roy. Soc. Edin.*, xlv., 201, 1906.

boiling point of their solutions. The curves, fig. 10, for which percentage hydration for both freezing and boiling points are plotted against the number of gramme equivalents per litre, indicate that for lithium chloride and calcium chloride the percentage hydration is greater at the lower temperature for the same concentration. As, however, salts are generally more soluble at high than at low temperatures, it will be seen that the maximum hydration for calcium chloride and lithium chloride from freezing-point observations and boiling-point observations are almost the same.

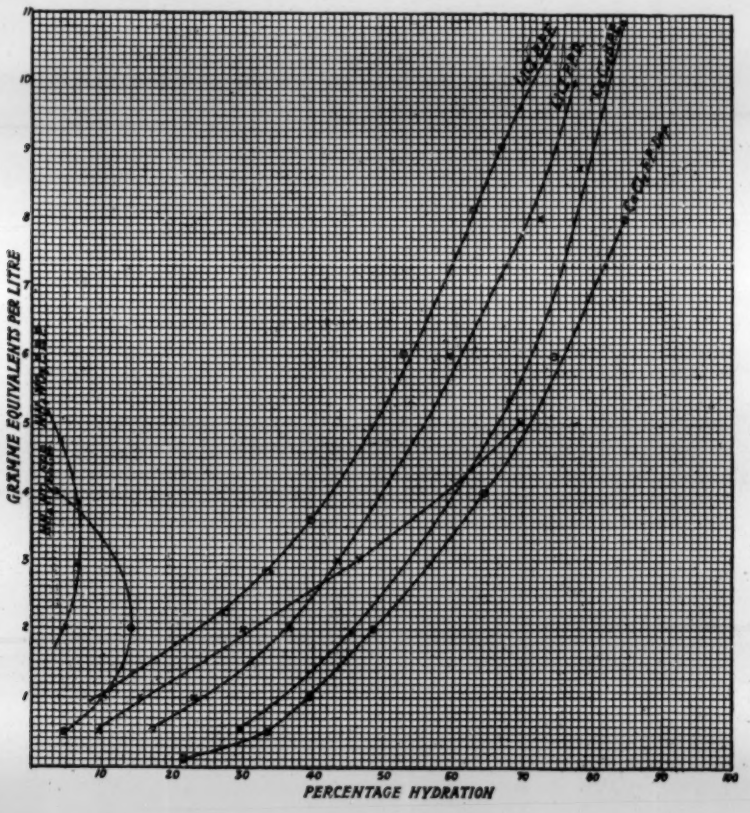

FIG. 10.

In fig. 11, p. 881, curves have been drawn for which gramme equivalents per litre have been plotted against percentage hydration at the boiling point. These show that for those salts which hydrate least there is a falling off of hydration for the higher concentrations, whilst for those which hydrate most the maximum hydration does not decrease, but reaches a stationary value, or a value approximately so. The above curves also show that the amount of hydration at the same concentration differs very considerably for the various salts, and that the maximum hydration also varies with the salt. For some salts it is very much greater than for others, but has not been obtained greater than 85 per cent.

For several salts, such as sodium bromide, chloride, and iodide and potassium iodide, the above tables show that the number of molecules of water of hydration per molecule of dissolved substance is almost constant for the salt under consideration, whether we view hydration as molecular and ionic, or only ionic. So that from the point of view

of constancy of hydration values an indication is scarcely given as to whether for the above salts the hydration is only ionic or both molecular and ionic. None of the salts above mentioned give a high percentage hydration.

For lithium chloride, bromide, and iodide, strontium bromide, and calcium bromide, on

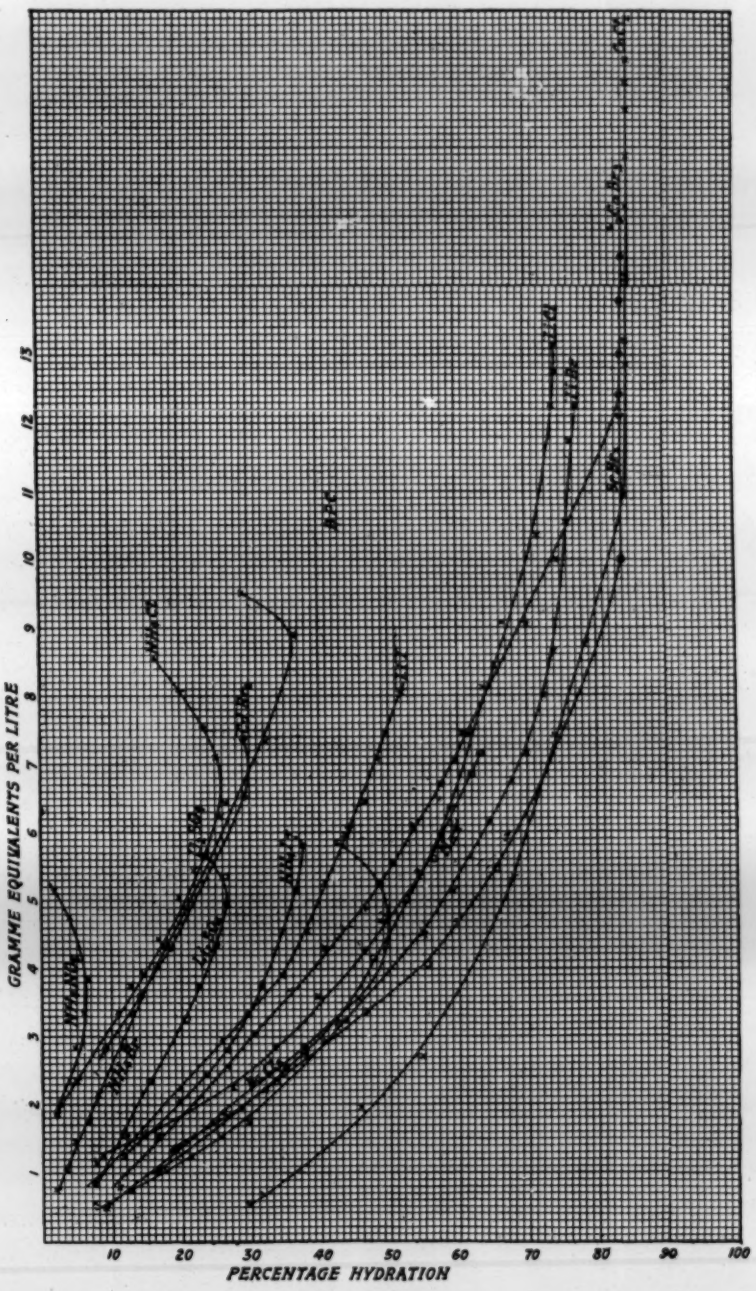

FIG. 11.

the supposition that both molecules and ions hydrate, there is a good degree of constancy in hydration values * up to a concentration of from 5 to 8 gramme equivalents per litre. The constancy of the number of molecules of hydration in these several instances is scarcely less than striking if the number of experiments and curve readings which enter

* Tables, pages 872 and 874.

into a final computation be remembered, not to speak of the calculations. Into every final computation there entered at least five experiments and two curve readings or interpolations. The agreement above mentioned is sufficient to suggest, for the chloride, iodide, and bromide of lithium, also for strontium bromide, that up to a concentration of 4 or 5 gramme molecules per litre the same quantity has been measured, or in other words, that for these salts the hydration is both molecular and ionic.

For each of these salts—that is, lithium chloride, etc., as above—the hydration found per ion on the assumption that ions only hydrate increases with concentration up to the highest concentration. This would seem improbable, and is sufficient to suggest that there is hydration other than ionic. For each of the salts the degree of hydration per molecule, on the assumption that molecules only hydrate, diminishes with increase of concentration, and no indication is given from this standpoint as to whether hydration is molecular, or ionic, or both. Consequently, for some salts, notably some of those showing the larger hydration capacity, there is evidence that both molecules and ions hydrate; for others which hydrate less the figures are indeterminate in their significance, as there is almost equal constancy, whether we view hydration as ionic or both ionic and molecular. A third class, as some of the ammonia salts, indicate that the ions only hydrate, as hydration ceases with ionization. To these perhaps another class should be added, such as zinc * sulphate and magnesium sulphate, for which the values of the elevation constant found are smaller than the theoretical value, which indicates that the molecules of these salts associate or enter into combination with each other.

Observations were made at very high concentrations for calcium chloride and bromide, for lithium chloride and bromide, and for strontium bromide, not only to find out how the maximum hydration would vary and what it would become for such concentrations, but also to see what it would become per molecule of dissolved substance or per molecule in solution, with a view to ascertaining whether the molecules of water of hydration at high concentration might or might not become less than the water of crystallization of the salt. The results showed that for calcium chloride the molecules of hydration water per molecule of dissolved substance fell off to 1·9. The salt takes up six molecules of water of crystallization. It thus appears that in this instance the water of hydration per molecule may be very much less than the water of crystallization. The minimum hydration per molecule of dissolved substance for calcium bromide obtained was 3·3. The salt crystallizes with six molecules of water. The minimum hydration per molecule for strontium bromide found was 4·0; the salt having six molecules of water of crystallization. Lithium chloride and lithium bromide each crystallize with two molecules of water of crystallization, and the smallest hydration values obtained per molecule were 1·9 and 2·3 respectively.

Consequently the results obtained for these several salts as to their hydrations per molecule indicate that, for those salts which hydrate with six molecules of water of

* Page 871.

crystallization, the hydration per molecule may be reduced considerably be number of molecules of water of crystallization; but for salts like lithium chlo bromide, which crystallize with only two molecules of water of crystallizat minimum water of hydration per molecule is approximately equal to the crystallization. For the salts of ammonia series of experiments are gi concentrated solutions; those for the more dilute solutions have already been For these salts generally there is decrease of hydration for the most conc solutions, but this is most noticeable with the nitrate, sulphate and chloride, an for the iodide and bromide.

Résumé.

(1) A minimum point has been found in most of the curves for which equivalents per litre have been plotted against elevation per gramme equivalent

(2) An increase in elevation per gramme equivalent has usually been fou increase of concentration for higher concentrations than that corresponding minimum point, but the rate of increase with concentration falls off for the concentrations. It has been found that for ammonium chloride the eleva gramme equivalent falls off for the higher concentrations after a certain conce is reached.

(3) The rate of increase of elevation of the boiling point falls off quickly higher concentrations for calcium chloride and lithium bromide, and for sever salts for which observations of elevation of the boiling point have been mad increase of elevation is compared with the number of grammes of salt adde solution.

(4) For some salts a much larger maximum percentage hydration has bee than for others. The more deliquescent salts gave the higher percentage hydra

(5) The maximum percentage hydration for the same salt does not materiall whether it be determined at the boiling or freezing point of the solution.

(6) For the higher temperature the maximum value is obtained at a hig centration. At the same concentration there is usually a greater percentage h at the lower than at the higher temperature.

(7) The number of molecules of water of hydration per molecule of salt for concentrated solution may be less than the number of molecules of water of cry tion. If the salt considered takes up as many as six molecules of crystallizatio it has been found to be much less.

(8) On the assumption of both ionic and molecular hydration for several s hydration values obtained indicate by their constancy up to varying concentrat correctness of the assumption.

(9) For other salts the indication as to ionic or molecular and ionic hydratio

* *Trans. Roy. Soc. Edin.*, xlv., 233, 1906.

conclusive, but for some it would seem that hydration ceases with ionization, and for these the indication is that there is only ionic hydration.

(10) The maximum hydration for some salts remains constant; for others there is a maximum point in the hydration curve.

(11) The curves for which equivalent elevation values are plotted against concentration may be quite similar in form for a salt and an acid ($CaBr_2$ and H_2SO_4, fig. 2).

(12) For the most concentrated solutions of nitric and hydrochloric acid the percentage hydration falls off when computed from observations made at the freezing point. From computations made at the boiling point it appears that equivalent elevation falls off for hydrochloric acid as the concentration increases, after a certain concentration is reached (fig. 2).

(13) Values of μ_v/μ_∞ are greater at the lower temperature for the same concentration for dilute solutions than at the higher temperatures; the reverse is true for the concentrated solutions; that is, the isothermals cross each other (fig. 6).

My warmest thanks are heartily given to Professor MacGregor for his kindly interest in this research.

I wish also to express my gratitude to the Moray Endowment and Carnegie Trust for grants towards the expense of this research.

Physical Laboratory,
Edinburgh University.

APPENDIX.

TRANSACTIONS

OF THE

ROYAL SOCIETY OF EDINBURGH.

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AND LIST OF HONORARY FELLOWS,

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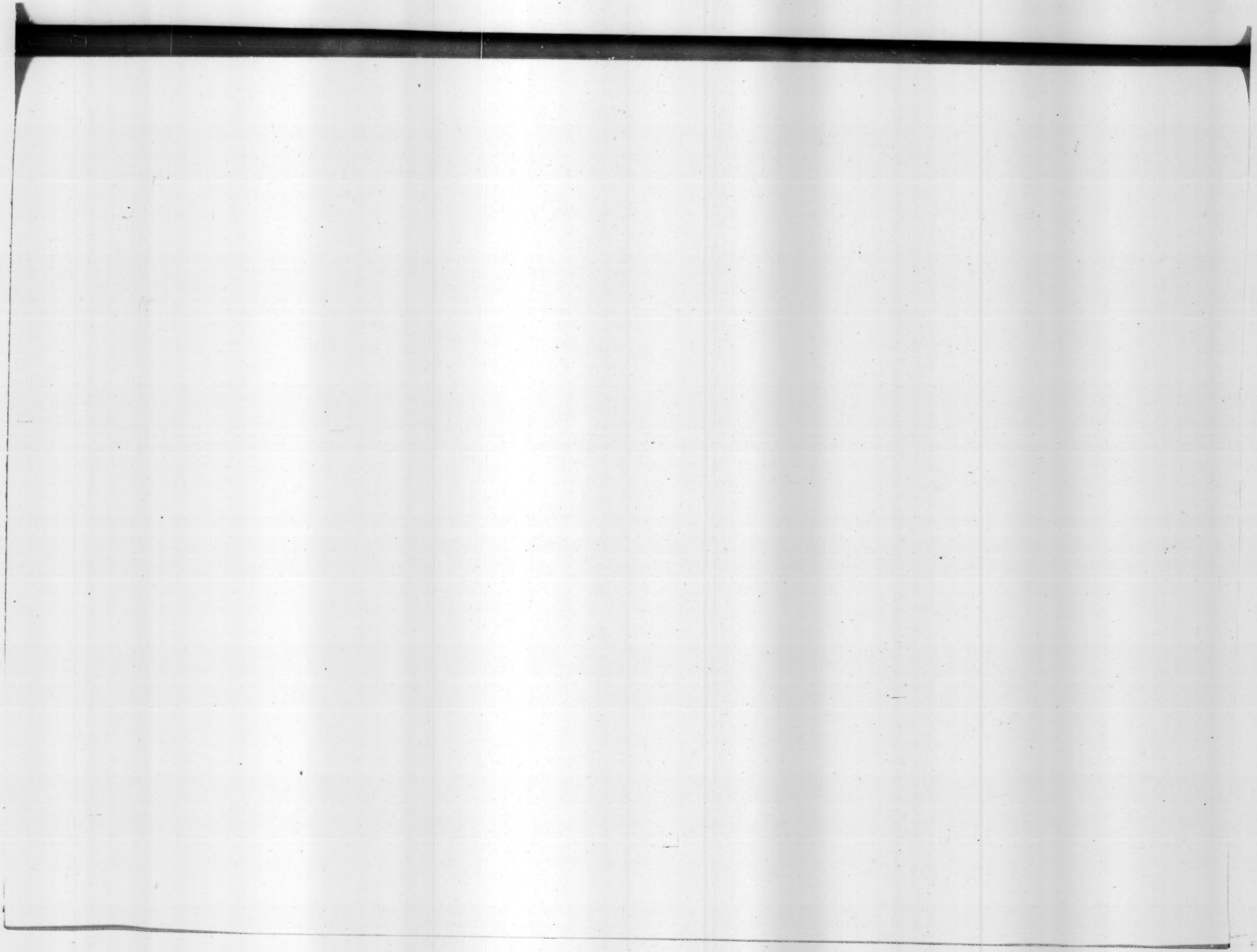

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OF

THE ROYAL SOCIETY OF EDINBURGH.

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OF

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CORRECTED TO OCTOBER 1907.

N.B.—*Those marked * are Annual Contributors.*

B. prefixed to a name indicates that the Fellow has received a Makdougall-Brisbane Medal.
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N. ,, ,, ,, Neill Medal.
V. J. ,, ,, ,, the Gunning Victoria Jubilee Prize.
C. ,, ,, ,, contributed one or more Communications to the Society's Transactions or Proceedings.

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1894		Allan, Francis John, M.D., C.M. Edin., M.O.H., City of Westminster, Westminster City Hall, Charing Cross Road, London
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1883		Anderson, Sir Robert Rowand, LL.D., 16 Rutland Square
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1882	C.	Barnes, Henry, M.D., LL.D., 6 Portland Square, Carlisle
1893		Barnes, R. S. Fancourt, M.D., M.R.C.P.L., Consulting Physician to the Royal Maternity Charity of London, 15 Chester Terrace, Regent's Park, London
1904		Barr, Sir James, M.D., F.R.C.P. Lond., 72 Rodney Street, Liverpool
1874		Barrett, William F., F.R.S., M.R.I.A., Prof. of Physics, Royal College of Science, Dublin
1889		Barry, T. D. Collis, Staff Surgeon, M.R.C.S., F.L.S., Chemical Analyser to the Government of Bombay, and Prof. of Chemistry and Medical Jurisprudence to the Grant Medical College, and of Chemistry, Elphinstone College, Malabar Hill, Bombay
1887		* Bartholomew, J. G., F.R.G.S., The Geographical Institute, Dalkeith Road
1895	C.	Barton, Edwin H., D.Sc., A.M.I.E.E., Memb. Phys. Soc. of London, Professor of Experimental Physics, University College, Nottingham
1904		* Baxter, William Muirhead, 2A Merchiston Place
1888		* Beare, Thomas Hudson, B.Sc., Memb. Inst. C.E., Professor of Engineering in the University of Edinburgh
1897	C.	* Beattie, John Carruthers, D.Sc., Professor of Physics, South African College, Cape Town
1892		Beck, J. H. Meining, M.D., M.R.C.P.E., Rondebosch, Cape Town
1893	B. C.	* Becker, Ludwig, Ph.D., Regius Professor of Astronomy in the University of Glasgow, The Observatory, Glasgow
1882	C.	Beddard, Frank E., M.A. Oxon., F.R.S., Prosector to the Zoological Society of London, Zoological Society's Gardens, Regent's Park, London
1887		* Begg, Ferdinand Faithful, Bartholomew House, London
1886		* Bell, A. Beatson, 17 Lansdowne Crescent
1906		Bell, John Patrick Fair, F.Z.S., Fulforth, Witton Gilbert, Durham
1874		Bell, Joseph, M.D., F.R.C.S.E., 2 Melville Crescent

Date of Election.		
1900		* Bennett, James Bower, Memb. Inst. C.E., 12 Hill Street
1887		* Bernard, J. Mackay, of Dunsinnan, B.Sc., Dunsinnan, Perth
1875		Bernstein, Ludwik, M.D., Lismore, New South Wales
1893	C.	* Berry, George A., M.D., C.M., F.R.C.S., 31 Drumsheugh Gardens
1897	C.	* Berry, Richard J., M.D., F.R.C.S.E., Professor of Anatomy in the University of Melbourne, Victoria
1904		* Beveridge, Erskine, LL.D., St Leonard's Hill, Dunfermline
1886	C.	Birch, De Burgh, M.D., Professor of Physiology in the University of Leeds, 16 De Grey Terrace, Leeds
1900		* Bisset, James, M.A., F.L.S., F.G.S., 9 Greenhill Park
1907		* Black, Frederick Alexander, Solicitor, 59 Academy Street, Inverness
1884		* Black, John S., M.A., LL.D. (Curator of Library and Museum), 6 Oxford Terrace
1850		Blackburn, Hugh, M.A., LL.D., Emeritus Professor of Mathematics in the University of Glasgow, Roshven, Lochailort
1897		* Blaikie, Walter Biggar, 6 Belgrave Crescent
1904	C.	* Bles, Edward J., M.A., D.Sc., Zoological Station, Trieste, Austria
1898	C.	* Blyth, Benjamin Hall, M.A., Memb. Inst. C.E., 17 Palmerston Place
1894		* Bolton, Herbert, F.G.S., F.L.S., Curator of the Bristol Museum, Queen's Road, Bristol
1884		Bond, Francis T., B.A., M.D., M.R.C.S., Gloucester
1872	C.	Bottomley, J. Thomson, M.A., D.Sc., LL.D., F.R.S., F.C.S., 13 University Gardens, Glasgow
1869	C.	Bow, Robert Henry, C.E., 7 South Gray Street
1886		* Bower, Frederick O., M.A., D.Sc., F.R.S., F.L.S., Regius Professor of Botany in the University of Glasgow, 1 St John's Terrace, Hillhead, Glasgow
1884	C.	Bowman, Frederick Hungerford, D.Sc., F.C.S. (Lond. and Berl.), F.I.C., Assoc. Inst. C.E., Assoc. Inst. M.E., M.I.E.E., &c., 4 Albert Square, Manchester
1901		Bradbury, J. B., M.D., Downing Professor of Medicine, University of Cambridge
1903	C.	* Bradley, O. Charnock, M.D., D.Sc., Royal Veterinary College, Edinburgh
1886		* Bramwell, Byrom, M.D., F.R.C.P.E., 23 Drumsheugh Gardens
1907		* Bramwell, Edwin, M.B., F.R.C.P.E., M.R.C.P. Lond., 23 Drumsheugh Gardens
1895		* Bright, Charles, Assoc. Memb. Inst. C.E., Memb. Inst. E.E., F.R.A.S., F.G.S., Parliament Chambers, London, S.W.
1877		Broadrick, George, Memb. Inst. C.E., Broughton House, Broughton Road, Ipswich
1893		Brock, G. Sandison, M.D., 6 Corso d'Italia, Rome, Italy
1892		* Brock, W. J., M.B., D.Sc., 5 Manor Place
1901	C.	* Brodie, W. Brodie, M.B., Thaxted, Essex
1907		Brown, Alexander, M.A., B.Sc., Professor of Applied Mathematics, South African College, Cape Town
1864	C. K. B.	Brown, Alex. Crum, M.D., D.Sc., F.R.C.P.E., LL.D., F.R.S. (Vice-President), Professor of Chemistry in the University of Edinburgh, 8 Belgrave Crescent
1898		* Brown, David, F.C.S., F.I.C., Willowbrae House, Midlothian
1883	C.	Brown, J. J. Graham, M.D., F.R.C.P.E., 3 Chester Street
1885	C.	Brown, J. Macdonald, M.D., F.R.C.S., 2 Frognal, London, N.W.
1883	C.	Bruce, Alexander, M.A., M.D., F.R.C.P.E., 8 Ainslie Place
1906		* Bruce, William Spiers, LL.D., Antarctica, Joppa, Midlothian
1898	K.C.	* Bryce, T. H., M.A., M.D. (Edin.), 2 Granby Terrace, Glasgow
1870	C. K.	Buchanan, John Young, M.A., F.R.S., Christ's College, Cambridge

Date of Election.		
1902		* Buchanan, Robert M., M.B., F.F.P.S.G., 2 Northbank Terrace, Glasgow
1882		Buchanan, T. R., M.A., M.P., 12 South Street, Park Lane, London, W.
1887	C.	* Buist, J. B., M.D., F.R.C.P.E., 1 Clifton Terrace
1905		Bunting, Thomas Lowe, M.D., Scotswood, Newcastle-on-Tyne 95
1902		* Burgess, A. G., M.A., Mathematical Master, Edinburgh Ladies' College, 2 Craigcrook Terrace Blackhall
1894	C. K.	* Burgess, James, C.I.E., LL.D., M.R.A.S., M. Soc. Asiatique de Paris, *H.*A.R.I.B.A., 22 Seton Place
1902		* Burn, The Rev. John Henry, B.D., The Parsonage, Ballater
1887		* Burnet, John James, Architect, 18 University Avenue, Hillhead, Glasgow
1888		* Burns, Rev. T., D.D., F.S.A. Scot., Minister of Lady Glenorchy's Parish Church, Croston Lodge, Chalmers Crescent 100
1896		* Butters, J. W., M.A., B.Sc., Rector of Ardrossan Academy
1887	C.	* Cadell, Henry Moubray, of Grange, B.Sc., Bo'ness
1897		* Caird, Robert, LL.D., Shipbuilder, Greenock
1893	C.	Calderwood, W. L., Inspector of Salmon Fisheries of Scotland, 7 East Castle Road, Merchiston
1894		* Cameron, James Angus, M.D., Medical Officer of Health, Firhall, Nairn 105
1905	C.	Cameron, John, M.D., D.Sc., M.R.C.S. Eng., Demonstrator of Anatomy, University of Manchester, Anatomy Department, Owens College, Manchester
1904		* Campbell, Charles Duff, 21 Montague Terrace, Inverleith Row
1899	C.	* Carlier, Edmund W. W., M.D., B.Sc., Prof. of Physiology in Mason College, Birmingham
1902		* Carmichael, Sir Thomas D. Gibson, Bart., M.A., Malleny House, Balerno
1906		Carruthers, John Bennett, F.L.S., Assoc. R.B.S., Director of Agriculture and Government Botanist, F.M.S., Kuala Lumpur, Federated Malay States 110
1905	C.	* Carse, George Alexander, M.A., B.Sc., Lecturer on Natural Philosophy, University of Edinburgh, 120 Lauriston Place
1901		Carslaw, H. S., M.A., D.Sc., Professor of Mathematics in the University of Sydney, New South Wales
1905		Carter, Joseph Henry, F.R.C.V.S., Stone House, Church Street, Burnley, Lancashire
1898		* Carter, Wm. Allan, Memb. Inst. C.E., 32 Great King Street
1898		Carus-Wilson, Cecil, F.R.G.S., F.G.S., Royal Societies Club, St James Street, London 115
1882		Cay, W. Dyce, Memb. Inst. C.E., 1 Albyn Place
1890		Charles, John J., M.A., M.D., C.M., late Prof. of Anatomy and Physiology, Queen's College, Cork, Karlsruhe, Port Stewart, Co. Derry
1899		* Chatham, James, Actuary, 7 Belgrave Crescent
1874		Chiene, John, C.B., M.D., LL.D., F.R.C.S.E., Professor of Surgery in the University of Edinburgh, 26 Charlotte Square
1880	C. K.	Chrystal, George, M.A., LL.D., Professor of Mathematics in the University of Edinburgh (General Secretary), 5 Belgrave Crescent 120
1891		* Clark, John B., M.A., Mathematical and Physical Master in Heriot's Hospital School, Garleffin, Craiglea Drive
1903		* Clarke, William Eagle, F.L.S., Keeper of the Natural History Collections in the Royal Scottish Museum, Edinburgh, 35 Braid Road
1875		Clouston, T. S., M.D., LL.D., Vice-President of the Royal College of Physicians, Tipperlinn House, Morningside
1892		* Coates, Henry, Pitcullen House, Perth

Date of Election.		
1887		* Cockburn, John, F.R.A.S., The Abbey, North Berwick 125
1904	C.	Coker, Ernest George, M.A., D.Sc., Professor of Mechanical Engineering and Applied Mechanics, City and Guilds Technical College, Finsbury, Leonard Street, City Road, London, E.C.
1904		Coles, Alfred Charles, M.D., D.Sc., York House, Poole Road, Bournemouth, W.
1888	C.	Collie, John Norman, Ph.D., F.R.S., F.C.S., Professor of Organic Chemistry in the University College, Gower Street, London
1904	C.	* Colquhoun, Walter, M.A., M.B., 7 Stanley Street, Glasgow, W.
1886		Connan, Daniel M., M.A. 130
1872		Constable, Archibald, LL.D., 11 Thistle Street
1894		Cook, John, M.A., Principal of the Government Central College, Bangalore, India
1891		* Cooper, Charles A., LL.D., 41 Drumsheugh Gardens
1905		* Corrie, David, F.C.S., Nobel's Explosives Company, Polmont Station
1875		Craig, William, M.D., F.R.C.S.E., Lecturer on Materia Medica to the College of Surgeons, 71 Bruntsfield Place 135
1907		* Cramer, William, Ph.D., Lecturer in Physiological Chemistry in the University of Edinburgh, Physiological Department, The University
1898		* Crawford, Francis Chalmers, 19 Royal Terrace
1903		Crawford, Lawrence, M.A., D.Sc., Professor of Mathematics in the South African College, Cape Town
1887		* Crawford, William Caldwell, 1 Lockharton Gardens, Colinton Road
1870		Crichton-Browne, Sir Jas., M.D., LL.D., F.R.S., Lord Chancellor's Visitor and Vice-President of the Royal Institution of Great Britain, 72 Queen's Gate, and Royal Courts of Justice, Strand, London 140
1886		* Croom, Sir John Halliday, M.D., F.R.C.P.E., Professor of Midwifery in the University of Edinburgh, Vice-President, Royal College of Surgeons, Edinburgh, 25 Charlotte Square
1898		* Cullen, Alexander, F.S.A. Scot., Millburn House, by Hamilton
1878	C.	Cunningham, Daniel John, M.D., LL.D., D.C.L., F.R.S., F.Z.S., Professor of Anatomy in the University of Edinburgh (SECRETARY), 18 Grosvenor Crescent
1898		* Currie, James, M.A. Cantab. (TREASURER), Larkfield, Golden Acre
1904		* Cuthbertson, John, Secretary, West of Scotland Agricultural College, 4 Charles Street, Kilmarnock 145
1889		* Dalrymple, James D. G., F.S.A. Lond. and Scot., Meiklewood, Stirling
1885		* Daniell, Alfred, M.A., LL.B., D.Sc., Advocate, The Athenæum Club, Pall Mall, London
1884		Davy, R., F.R.C.S. Eng., Consulting Surgeon to Westminster Hospital, Burstone House, Bow, North Devon
1894		* Denny, Archibald, Braehead, Dumbarton
1869	C. V. J.	Dewar, Sir James, M.A., LL.D., D.C.L., D.Sc. Dub., F.R.S., F.C.S., Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge, and Fullerian Professor of Chemistry at the Royal Institution of Great Britain, London 150
1905		* Dewar, James Campbell, C.A., 27 Douglas Crescent
1906		* Dewar, Thomas Wm., M.D., F.R.C.P., Kincairn, Dunblane
1904		Dickinson, Walter George Burnett, F.R.C.V.S., Boston, Lincolnshire
1884		* Dickson, The Right Hon. Charles Scott, K.C., LL.D., 22 Moray Place

Date of Election.		
1888	C.	* Dickson, Henry Newton, M.A., D.Sc., "The Lawn," Upper Redlands Road, Reading 155
1876	C.	Dickson, J. D. Hamilton, M.A., Fellow and Tutor, St Peter's College, Cambridge
1885	C.	Dixon, James Main, M.A., President, Columbia College, Milton, Oregon, United States
1897		* Dobbie, James Bell, F.Z.S., 2 Hailes Street
1904	C.	* Dobbie, James Johnston, M.A., D.Sc., F.R.S., Director of the Royal Scottish Museum, Edinburgh, 27 Polwarth Terrace
1881	C.	Dobbin, Leonard, Ph.D., Lecturer on Chemistry in the University of Edinburgh, 6 Wilton Road 160
1902		Dollar, John A. W., M.R.C.V.S., 56 New Bond Street, London
1867	C.	Donaldson, Sir James, M.A., LL.D., Principal of the University of St Andrews, St Andrews
1896		* Donaldson, William, M.A., Viewpark House, Spylaw Road
1905		* Donaldson, Rev. Wm. Galloway, Minister of St Paul's Parish, 11 Claremont Crescent
1882	C.	Dott, David B., F.I.C., Memb. Pharm. Soc., Ravenslea, Musselburgh 165
1892		Doyle, Patrick, C.E., M.R.I.A., F.G.S., Editor of *Indian Engineering*, Calcutta
1901		* Douglas, Carstairs Cumming, M.D., D.Sc., Professor of Medical Jurisprudence and Hygiene, Anderson's College, Glasgow, 2 Royal Crescent, Glasgow
1866		Douglas, David, 22 Drummond Place
1901		* Drinkwater, Thomas W., L.R.C.P.E., L.R.C.S.E., 25 Blacket Place
1878		Duncanson, J. J. Kirk, M.D., F.R.C.P.E., 22 Drumsheugh Gardens 170
1904		* Dunlop, William Brown, M.A., 7 Carlton Street
1859	C.	Duns, Rev. Professor, D.D., 5 Greenhill Place
1903		* Dunstan, John, M.R.C.V.S., 1 Dean Terrace, Liskeard, Cornwall
1892	C.	Dunstan, M. J. R., M.A., F.I.C., F.C.S., Principal, South-eastern Agricultural College, Wye, Kent
1899		* Duthie, George, M.A., Inspector-General of Education, Salisbury, Rhodesia 175
1906		* Dyson, Frank Watson, M.A., F.R.S., Astronomer Royal for Scotland, and Professor of Astronomy in the University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh
1893		Edington, Alexander, M.D., Colonial Bacteriologist, Graham's Town, South Africa
1904		* Edwards, John, 4 Great Western Terrace, Kelvinside, Glasgow
1904		* Elder, William, M.D., F.R.C.P.E., 4 John's Place, Leith
1885		Elgar, Francis, Memb. Inst. C.E., LL.D., F.R.S., 18 Cornwall Terrace, Regent's Park, London 180
1875		Elliot, Daniel G., Curator of Department of Zoology, Field Columbian Museum, Chicago, U.S.
1906	C.	* Ellis, David, D.Sc., Ph.D., Lecturer in Botany and Bacteriology, Glasgow and West of Scotland Technical College, Glasgow
1897	C.	* Erskine-Murray, James Robert, D.Sc., 219 St Vincent Street, Glasgow
1884		* Evans, William, F.F.A., 38 Morningside Park
1879	C. N.	Ewart, James Cossar, M.D., F.R.C.S.E., F.R.S., F.L.S., Regius Professor of Natural History, University of Edinburgh (VICE-PRESIDENT), Duddingston House, Duddingston, Midlothian 185
1902		* Ewen, J. T., B.Sc., Memb. Inst. Mech. E., H.M.I.S., 104 King's Gate, Aberdeen
1878	C.	Ewing, James Alfred, M.A., B.Sc., LL.D., Memb. Inst. C.E., F.R.S., Director of Naval Education, Royal Naval College, Greenwich
1900		Eyre, John W. H., M.D., M.S. (Dunelm), D.P.H. (Camb.), Guy's Hospital (Bacteriological Department), London
1875		Fairley, Thomas, Lecturer on Chemistry, 8 Newton Grove, Leeds

Date of Election.		
1907	C.	Falconer, John Downie, M.A., D.Sc., F.G.S., Director, Mineral Survey of Northern Nigeria, The Limes, Little Berkhampstead, Hertford, and Imperial Institute, London 190
1888	C.	* Fawsitt, Charles A., 9 Foremount Terrace, Dowanhill, Glasgow
1883	C.	Felkin, Robert W., M.D., F.R.G.S., Fellow of the Anthropological Society of Berlin, 12 Oxford Gardens, North Kensington, London, W.
1899		* Fergus, Andrew Freeland, M.D., 22 Blythswood Square, Glasgow
1907		* Fergus, Edward Oswald, 12 Clairmont Gardens, Glasgow
1904		* Ferguson, James Haig, M.D., F.R.C.P.E., F.R.C.S.E., 7 Coates Crescent 195
1888		* Ferguson, John, M.A., LL.D., Professor of Chemistry in the University of Glasgow
1868	C.	Ferguson, Robert M., Ph.D., LL.D. (Society's Representative on George Heriot's Trust), 5 Douglas Gardens
1898		* Findlay, John R., M.A. Oxon., 27 Drumsheugh Gardens
1899		* Finlay, David W., B.A., M.D., LL.D., F.R.C.P., D.P.H., Professor of Medicine in the University of Aberdeen, 2 Queen's Terrace, Aberdeen
1906		* Fleming, Robert Alexander, M.D., F.R.C.P.E., Assistant Physician, Royal Infirmary, 10 Chester Street 200
1900	C.N.	* Flett, John S., M.A., D.Sc., Geological Survey Office, 28 Jermyn Street, London
1880		Flint, Robert, D.D., Corresponding Member of the Institute of France, Corresponding Member of the Royal Academy of Sciences of Palermo, Emeritus Professor of Divinity in the University of Edinburgh, 5 Royal Terrace
1872	C.	Forbes, Professor George, M.A., Memb. Inst. C.E., Memb. Inst. E.E., F.R.S., F.R.A.S., 34 Great George Street, Westminster
1904		Forbes, Norman Hay, F.R.C.S.E., Druminnor, Church Stretton, Salop
1892		* Ford, John Simpson, F.C.S., 4 Nile Grove 205
1858		Fraser, A. Campbell, Fellow of the British Academy, Hon. D.C.L. Oxford, LL.D., Litt.D., Emeritus Professor of Logic and Metaphysics in the University of Edinburgh, Gorton House, Hawthornden
1896		* Fraser, John, M.B., F.R.C.P.E., one of H.M. Commissioners in Lunacy for Scotland, 13 Heriot Row
1867	C K. B.	Fraser, Sir Thomas R., M.D., LL.D., F.R.C.P.E., F.R.S., Professor of Materia Medica in the University of Edinburgh, Honorary Physician to the King in Scotland, 13 Drumsheugh Gardens
1891		* Fullarton, J. H., M.A., D.Sc., Brodick, Arran
1891		* Fulton, T. Wemyss, M.D., Scientific Superintendent, Scottish Fishery Board, 417 Great Western Road, Aberdeen 210
1907		* Galbraith, Alexander, Organiser of Continuation Classes in Science, Glasgow and West of Scotland Technical College, 4 Maxwell Square, Pollokshields, Glasgow
1888	C.	* Galt, Alexander, D.Sc., Keeper of the Technological Department, Royal Scottish Museum, Edinburgh
1901		Ganguli, Sanjiban, M.A., Principal, Maharaja's College, and Director of Public Instruction, Jaipur States, Jaipur, India
1899		Gatehouse, T. E., Assoc. Memb. Inst. C.E., Memb. Inst. M.E., Memb. Inst. E.E., Tulse Hill Lodge, 100 Tulse Hill, London
1867		Gayner, Charles, M.D., F.L.S. 215
1900		Gayton, William, M.D., M.R.C.P.E., Ravensworth, Regents Park Road, Finchley, London, N.

Date of Election.		
1880	C.	Geddes, Patrick, Professor of Botany in University College, Dundee, and Lecturer on Zoology, Ramsay Garden, University Hall, Edinburgh
1861	C. B.	Geikie, Sir Archibald, K.C.B., D.C.L., Oxf., D.Sc. Camb. Dub., LL.D., St And., Glasg., Aberdeen, Edin., Ph.D., Upsala, Sec. R.S., Pres. G.S., Foreign Member of the Reale Accad. Lincei, Rome, of the National Acad. of the United States, of the Academies of Stockholm, Christiania, Göttingen, Corresponding Member of the Institute of France and of the Academies of Berlin, Vienna, Munich, Turin, Belgium, Philadelphia, New York, &c., Shepherd's Down, Haslemere, Surrey
1871	C. B.	Geikie, James, LL.D., D.C.L., F.R.S., F.G.S., Professor of Geology in the University of Edinburgh, Kilmorie, Colinton Road
1881	C.	Gibson, George Alexander, D.Sc., M.D., LL.D., F.R.C.P.E., 3 Drumsheugh Gardens 220
1890		* Gibson, George A., M.A., LL.D., Professor of Mathematics in the Glasgow and West of Scotland Technical College, 8 Sandyford Place, Glasgow
1877	C.	Gibson, John, Ph.D., Professor of Chemistry in the Heriot-Watt College, 20 George Square
1892		Gifford, Herbert James, Assoc. M. Inst. C.E.
1900		Gilchrist, Douglas A., B.Sc., Professor of Agriculture and Rural Economy, Armstrong College, Newcastle-upon-Tyne
1880		Gilruth, George Ritchie, Surgeon, 53 Northumberland Street 225
1907		Gilruth, John Anderson, M.R.C.V.S., Chief Veterinarian, N.Z. Government, and Pathologist to Public Health Department, N.Z., Wellington, New Zealand
1898		* Glaister, John, M.D., F.F.P.S. Glasgow, D.P.H. Camb., Professor of Forensic Medicine in the University of Glasgow, 3 Newton Place, Glasgow
1901		Goodwillie, James, M.A., B.Sc., Liberton, Edinburgh
1899		* Goodwin, Thomas S., M.B., C.M., F.C.S., 1 Heron Terrace, St Margaret's, Middlesex
1897		Gordon-Munn, John Gordon, M.D., 34 Dover Street, London, W. 230
1891		* Graham, Richard D., 11 Strathearn Road
1898	C.	* Gray, Albert A., M.D., 14 Newton Terrace, Glasgow
1883		Gray, Andrew, M.A., LL.D., F.R.S. (Vice-President), Professor of Natural Philosophy in the University of Glasgow
1880	C.	Gray, Thomas, B.Sc., Professor of Physics, Rose Polytechnic Institute, Terre Haute, Indiana, U.S.
1886		* Greenfield, W. S., M.D., F.R.C.P.E., Professor of General Pathology in the University of Edinburgh, 7 Heriot Row 235
1897		Greenlees, Thomas Duncan, M.D. Edin., The Residency, Grahamstown, South Africa
1905		* Gregory, John Walter, D.Sc., F.R.S., Professor of Geology in the University of Glasgow, 4 Park Quadrant, Glasgow
1906		Greig, Edward David Wilson, M.D., B.Sc., Captain, H.M.'s Indian Medical Service, Byculla Club, Bombay, India
1905		Greig, Robert Blyth, F.Z.S., Fordyce Lecturer in Agriculture, University of Aberdeen, Torloisk, Cults, Aberdeenshire
1899		* Guest, Edward Graham, M.A., B.Sc., 5 Church Hill 240
1907		* Gulliver, Gilbert Henry, Lecturer in Experimental Engineering in the University of Edinburgh, 5 Lauriston Park
1888	C.	Guppy, Henry Brougham, M.B., Rosario, Salcombe, Devon
1905	B. C.	* Halm, Jacob E., Ph.D., Chief Assistant Astronomer, Royal Observatory, Cape Town, Cape of Good Hope
1899		Hamilton, Allan M'Lane, M.D., 44 East Twenty-ninth Street, New York

Date of Election.		
1881	C.	Hamilton, D. J., M.B., F.R.C.S.E., LL.D., Professor of Pathological Anatomy in the University of Aberdeen, 35 Queen's Road, Aberdeen 245
1876	C.	Hannay, J. Ballantyne, Cove Castle, Loch Long
1902		* Hargreaves, Andrew Fuller, F.C.S., Eskhill House, Roslin
1896		* Harris, David, Fellow of the Statistical Society, Lyncombe Rise, Prior Park Road, Bath
1896	C.	* Harris, David Fraser, B.Sc. (Lond.), M.D., F.S.A. Scot., Lecturer on Physiology in the University of St Andrews
1888		* Hart, D. Berry, M.D., F.R.C.P.E., 5 Randolph Cliff 250
1869		Hartley, Sir Charles A., K.C.M.G., Memb. Inst. C.E., 26 Pall Mall, London
1877	C.	Hartley, W. N., D.Sc., F.R.S., F.I.C., Prof. of Chemistry, Royal College of Science for Ireland, Dublin
1881		Harvie-Brown, J. A., of Quarter, F.Z.S., Dunipace House, Larbert, Stirlingshire
1880	C.	Haycraft, J. Berry, M.D., D.Sc., Professor of Physiology in the University College of South Wales and Monmouthshire, Cardiff
1892	C.	* Heath, Thomas, B.A., Assistant Astronomer, Royal Observatory, Edinburgh 255
1862		Hector, Sir J., K.C.M.G., M.D., F.R.S., Director of the Geological Survey, Colonial Laboratory, Meteorological and Weather Departments, and of the New Zealand Institute, Wellington, New Zealand
1893		Hehir, Patrick, M.D., F.R.C.S.E., M.R.C.S.L., L.R.C.P.E., Surgeon-Captain, Indian Medical Service, Principal Medical Officer, H.H. the Nizam's Army, Hyderabad, Deccan, India
1890	C.	Helme, T. Arthur, M.D., M.R.C.P.L., M.R.C.S., 3 St Peter's Square, Manchester
1900		Henderson, John, D.Sc., Assoc. Inst. E.E., Kinnoul, Warwick's Bench Road, Guildford, Surrey
1890	C.	* Hepburn, David, M.D., Professor of Anatomy in the University College of South Wales and Monmouthshire, Cardiff 260
1881	C. N.	Herdman, W. A., D.Sc., F.R.S., Pres.L.S., Prof. of Natural History in the University of Liverpool, Croxteth Lodge, Ullet Road, Liverpool
1894		Hill, Alfred, M.D., M.R.C.S., F.I.C., Valentine Mount, Freshwater Bay, Isle of Wight
1902		* Hinxman, Lionel W., B.A., Geological Survey Office, 33 George Square
1904		Hobday, Frederick T. G., F.R.C.V.S., 6 Berkeley Gardens, Kensington, London
1885		Hodgkinson, W. R., Ph.D., F.I.C., F.C.S., Prof. of Chem. and Physics at the Royal Military Acad. and Royal Artillery Coll., Woolwich, 18 Glenluce Road, Blackheath, Kent 265
1881	C. N.	Horne, John, LL.D., F.R.S., F.G.S., Director of the Geological Survey of Scotland (Vice-President), 33 George Square, Edinburgh
1896		Horne, J. Fletcher, M.D., F.R.C.S.E., The Poplars, Barnsley
1904		* Horsburgh, Ellice Martin, M.A., B.Sc., Lecturer in Technical Mathematics, University of Edinburgh, 11 Granville Terrace
1897		Houston, Alex. Cruikshanks, M.B., C.M., D.Sc., 14 Upper Addison Gardens, Kensington, London
1893		Howden, Robert, M.A., M.B., C.M., Professor of Anatomy in the University of Durham, 14 Burdon Terrace, Newcastle-on-Tyne 270
1899		Howie, W. Lamond, F.C.S., 26 Neville Court, Abbey Road, Regents Park, London, N.W.
1883	C.	Hoyle, William Evans, M.A., D.Sc., M.R.C.S., 25 Brunswick Road, Withington, Manchester
1886		Hunt, Rev. H. G. Bonavia, Mus.D. Dub., Mus.B. Oxon., The Vicarage, Burgess Hill, Sussex
1887	C.	* Hunter, James, F.R.C.S.E., F.R.A.S., Rosetta, Liberton, Midlothian
1887	C.	* Hunter, William, M.D., M.R.C.P. L. and E., M.R.C.S., 54 Harley Street, London 275

Date of Election.		
1882	C.	Inglis, J. W., Memb. Inst. C.E., Kenwood, Barnton, Midlothian
1906		* Innes, Alexander Taylor, M.A., Advocate, 48 Morningside Park
1904	C.	Innes, R. T. A., Director, Government Observatory, Johannesburg, Transvaal
1904		* Ireland, Alexander Scott, S.S.C., 2 Buckingham Terrace
1875		Jack, William, M.A., LL.D., Professor of Mathematics in the University of Glasgow 280
1894		Jackson, Sir John, LL.D., 48 Belgrave Square, London
1889	C.	* James, Alexander, M.D., F.R.C.P.E., 14 Randolph Crescent
1882		Jamieson, Prof. A., Memb. Inst. C.E., 16 Rosslyn Terrace, Kelvinside, Glasgow
1901		* Jardine, Robert, M.D., M.R.C.S. Eng., F.F.P. and S. Glas., 20 Royal Crescent, Glasgow
1900		Jee, Sir Bhagvat Sinh, G.C.I.E., M.D., LL.D. Edin., H.H. The Thakore Sahib of Gondal, Gondal, Kathiawar, Bombay 285
1906	C.	* Jehu, Thomas James, M.A., M.D., F.G.S., Lecturer in Geology, University of St Andrews, Strathmartine, Hepburn Gardens, St Andrews
1900		* Jerdan, David Smiles, M.A., D.Sc., Ph.D., Temora, Colinton, Midlothian
1895		Johnston, Lieutenant-Colonel Henry Halcro, C.B., R.A.M.S., D.Sc., M.D., F.L.S., Orphir House, Kirkwall, Orkney
1903	C.	* Johnston, Thomas Nicol, M.B., C.M., Corstorphine House, Corstorphine
1906	C.	* Johnston, Rev. Samuel M., B.A., D.Sc., 2 Argyle Park Terrace 290
1902		Johnstone, George, Lieut. R.N.R., Marine Superintendent, British India Steam Navigation Co., 16 Strand Road, Calcutta, India
1874		Jones, Francis, M.Sc., Lecturer on Chemistry, Beaufort House, Alexandra Park, Manchester
1888		Jones, John Alfred, Memb. Inst. C.E., Fellow of the Univ. of Madras, Sanitary Engineer to the Government of Madras, c/o Messrs Parry & Co., 70 Gracechurch St., London
1905		Jones, George William, M.A., B.Sc., Coraldene, Kirk Brae, Liberton
1847	C. K. V. J.	Kelvin, The Right Hon. Lord, G.C.V.O., P.C., LL.D., D.C.L., F.R.S. (PRESIDENT), Grand Officer of the Legion of Honour of France, Member of the Prussian Order *Pour le Mérite*, Foreign Associate of the Institute of France, and Emeritus Professor of Natural Philosophy in the University of Glasgow, Netherhall, Largs, Ayrshire, and 15 Eaton Place, London, S.W. 295
1907		* Kemp, John, M.A., Headmaster, High School, Kelso
1892		* Kerr, Rev. John, M.A., Manse, Dirleton
1903	C. N.	* Kerr, John Graham, M.A., Professor of Zoology in the University of Glasgow
1891		Kerr, Joshua Law, M.D., Biddenden Hall, Cranbrook, Kent
1886	C. N.	* Kidston, Robert, F.R.S., F.G.S., 12 Clarendon Place, Stirling 300
1907		* King, Archibald, M.A., B.Sc., Rector of the Academy, Castle-Douglas, Hazeldene, Castle-Douglas, Kirkcudbrightshire
1877		King, Sir James, of Campsie, Bart., LL.D., 115 Wellington Street, Glasgow
1880		King, W. F., Lonend, Russell Place, Trinity
1883		Kinnear, The Rt. Hon. Lord, one of the Senators of the College of Justice, 2 Moray Place
1878		Kintore, The Right Hon. the Earl of, M.A. Cantab., LL.D. Cambridge, Aberdeen and Adelaide, Keith Hall, Inverurie, Aberdeenshire 305
1901		* Knight, The Rev. G. A. Frank, M.A., St Leonard's United Free Church, Perth
1907		* Knight, James, M.A., D.Sc., F.C.S., F.G.S., Headmaster, St James School, Glasgow, The Shieling, Uddingston, by Glasgow
1880	C. K.	Knott, C. G., D.Sc., Lecturer on Applied Mathematics in the University of Edinburgh (late Prof. of Physics, Imperial University, Japan), (SECRETARY), 42 Upper Gray Street, Edinburgh

Date of Election.		
1896	C.	* Kuenen, J. P., Ph.D. (Leiden), Prof. of Natural Philosophy in the University of Leiden, Holland
1886		* Laing, Rev. George P., 17 Buckingham Terrace 310
1907		* Lanchester, William Forster, M.A., Den of Gryffe, Kilmalcolm
1878	C.	Lang, P. R. Scott, M.A., B.Sc., Professor of Mathematics, University of St Andrews
1885	C.	* Laurie, A. P., M.A., D.Sc., Principal of the Heriot-Watt College, Edinburgh
1894	C.	* Laurie, Malcolm, B.A., D.Sc., F.L.S., Royal College of Surgeons, Edinburgh
1870		Laurie, Simon S., M.A., LL.D., Emeritus Professor of Education in the University of Edinburgh, 22 George Square 315
1905		* Lawson, David, M.A., M.D., L.R.C.P. and S.E., Druimdarroch, Banchory, Kincardineshire
1903		* Leighton, Gerald Rowley, M.D., Sunnyside, Russell Place
1874	C. K.	Letts, E. A., Ph.D., F.I.C., F.C.S., Professor of Chemistry, Queen's College, Belfast
1905		* Lightbody, Forrest Hay, 56 Queen Street
1889		* Lindsay, Rev. James, D.D., B.Sc., F.G.S., M.R.A.S., Corresponding Member of the Royal Academy of Sciences, Letters and Arts, of Padua, Associate of the Philosophical Society of Louvain, Minister of St Andrew's Parish, Springhill Terrace, Kilmarnock 320
1870	C. B.	Lister, The Right Hon. Lord, O.M., P.C., M.D., F.R.C.S.L., F.R.C.S.E., LL.D., D.C.L., F.R.S., Foreign Associate of the Institute of France, Emeritus-Prof. of Clinical Surgery, King's College, Surgeon Extraordinary to the King, 12 Park Crescent, Portland Place, London
1903		Liston, William Glen, M.D., Captain, Indian Medical Service, c/o Grindlay Groom & Co., Bombay, India
1903		* Littlejohn, Henry Harvey, M.A., M.B., B.Sc., F.R.C.S.E., Professor of Forensic Medicine in the University of Edinburgh, 11 Rutland Street
1898		* Lothian, Alexander Veitch, M.A., B.Sc., Glendoune, Manse Road, Bearsden, Glasgow
1884		* Low, George M., Actuary, 11 Moray Place 325
1888		* Lowe, D. F., M.A., LL.D., Head Master of Heriot's Hospital School, Lauriston
1904		* Lowson, Charles Stewart, M.B., C.M., Captain, Indian Medical Service, c/o Messrs Thomas Cook & Son, Bombay, India
1900		Lusk, Graham, Ph.D., M.A., Prof. of Physiology, Univ. and Bellevue Medical College, N.Y.
1894		* Mabbott, Walter John, M.A., Rector of County High School, Duns, Berwickshire
1887		M'Aldowie, Alexander M., M.D., Glengarriff, Leckhampton, Cheltenham 330
1907		MacAlister, Donald Alexander, A.R.S.M., F.G.S., 20 Hanover Square, London, W.
1891		Macallan, John, F.I.C., 3 Rutland Terrace, Clontarf, Dublin
1888	C.	M'Arthur, John, F.C.S., 196 Trinity Road, Wandsworth Common, London
1883		M'Bride, P., M.D., F.R.C.P.E., 16 Chester Street
1903		* M'Cormick, W. S., M.A., LL.D., 13 Douglas Crescent 335
1899		* M'Cubbin, James, B.A., Rector of the Burgh Academy, Kilsyth
1905		* Macdonald, Hector Munro, M.A., F.R.S., Professor of Mathematics, University of Aberdeen, 52 College Bounds, Aberdeen
1894		* Macdonald, James, Secretary of the Highland and Agricultural Society of Scotland, 2 Garscube Terrace
1897	C.	* Macdonald, James A., M.A., B.Sc., H.M. Inspector of Schools, Glengarry, Dingwall
1904		* Macdonald, John A., M.A., B.Sc., High School, Stellenbosch, Cape Colony 340

Date of Election.		
1886		* Macdonald, The Rt. Hon. Sir J. H. A., K.C.B., K.C., LL.D., F.R.S., M.I.E.E., Lord Justice-Clerk, and Lord President of the Second Division of the Court of Session, 15 Abercromby Place
1904		Macdonald, William, B.Sc., M.Sc., Agriculturist, Editor, Transvaal Agricultural Journal, Department of Agriculture, Pretoria Club, Pretoria, Transvaal
1886		* Macdonald, William J., M.A., Comiston Drive
1901	C.	* MacDougal, R. Stewart, M.A., D.Sc., 13 Archibald Place
1888	C.	* M'Fadyean, Sir John, M.B., B.Sc., LL.D., Principal, and Professor of Comparative Pathology in the Royal Veterinary College, Camden Town, London 345
1878	C.	Macfarlane, Alexander, M.A., D.Sc., LL.D., Lecturer in Physics in Lehigh University, Pennsylvania, Gowrie Grove, Chatham, Ontario, Canada
1885	C.	* Macfarlane, J. M., D.Sc., Professor of Botany and Director of the Botanic Garden, University of Pennsylvania, Philadelphia, Pennsylvania, U.S.A.
1897		* M'Gillivray, Angus, C.M., M.D., South Tay Street, Dundee
1878		M'Gowan, George, F.I.C., Ph.D., 21 Montpelier Road, Ealing, Middlesex
1886		* MacGregor, Rev. James, D.D., 3 Eton Terrace 350
1880	C.	MacGregor, James Gordon, M.A., D.Sc., LL.D., F.R.S., Prof. of Natural Philosophy in the University of Edinburgh, 24 Dalrymple Crescent
1903		* M'Intosh, D. C., M.A., B.Sc., 37 Warrender Park Terrace
1869	C. N.	M'Intosh, William Carmichael, M.D., LL.D., F.R.S., F.L.S., Professor of Natural History in the University of St Andrews, 2 Abbotsford Crescent, St Andrews
1895	C.	* Macintyre, John, M.D., 179 Bath Street, Glasgow
1882		Mackay, John Sturgeon, M.A., LL.D., late Mathematical Master in the Edinburgh Academy, 69 Northumberland Street 355
1873	C. B.	M'Kendrick, John G., M.D., F.R.C.P.E., LL.D., F.R.S., Emeritus Professor of Physiology in the University of Glasgow, Maxieburn, Stonehaven
1900	C.	* M'Kendrick, John Souttar, M.D., F.F.P.S.G., 2 Buckingham Terrace, Glasgow
1894		* Mackenzie, Robert, M.D., Napier, Nairn
1898		Mackenzie, W. Cossar, D.Sc., 5 The Crescent, Cromer
1904		* Mackenzie, W. Leslie, M.A., M.D., D.P.H., Medical Member of the Local Government Board for Scotland, 1 Stirling Road, Trinity 360
1905		Mackenzie, William Colin, M.D., F.R.C.S., Demonstrator of Anatomy in the University of Melbourne, Elizabeth Street North, Melbourne, Victoria
1904		* Mackintosh, Donald James, M.V.O., M.B., Supt. of the Western Infirmary, Glasgow
1869	C.	Maclagan, R. C., M.D., F.R.C.P.E., 5 Coates Crescent
1869	C.	M'Laren, The Hon. Lord, LL.D. Edin. & Glasg., F.R.A.S., one of the Senators of the College of Justice, 46 Moray Place
1899		Maclean, Ewan John, M.D., M.R.C.P London, 12 Park Place, Cardiff 365
1888	C.	* Maclean, Magnus, M.A., D.Sc., Memb. Inst. E.E., Prof. of Electrical Engineering in the Glasgow and West of Scotland Technical College, 51 Kerrsland Terrace, Hillhead, Glasgow
1876		Macleod, Very Rev. Norman, D.D., 74 Murrayfield Gardens
1876		Macmillan, John, M.A., D.Sc., M.B., C.M., F.R.C.P.E., 48 George Square
1893		* M'Murtrie, The Rev. John, M.A., D.D., 13 Inverleith Place
1906		* Macnair, Duncan Scott, Ph.D., B.Sc., H.M. Inspector of Schools, 67 Braid Avenue 370
1907		* Macnair, Peter, Curator of the Natural History Collections in the Glasgow Museums, Kelvingrove Museum, Glasgow

Date of Election.		
1884		* Macpherson, Rev. J. Gordon, M.A., D.Sc., Ruthven Manse, Meigle
1890		* M'Vail, John C., M.D., 20 Eton Place, Hillhead, Glasgow
1898	C.	Mahalanobis, S. C., B.Sc., Professor of Physiology, Presidency College, Calcutta, India
1880	C.	Marsden, R. Sydney, M.B., C.M., D.Sc., M.R.I.A., F.I.C., F.C.S., Rowallan House, Cearns Road, and Town Hall, Birkenhead 375
1882	C.	Marshall, D. H., M.A., Professor of Physics in Queen's University and College, Kingston, Ontario, Canada
1901	C.	* Marshall, F. H. A., M.A., D.Sc., Physiological Department, University of Edinburgh
1888	C. K.	* Marshall, Hugh, D.Sc., F.R.S., Lecturer on Chemistry and on Mineralogy and Crystallography in the University of Edinburgh, 12 Lonsdale Terrace
1892		* Martin, Francis John, W.S., 17 Rothesay Place
1903		Martin, Nicholas Henry, F.L.S., F.C.S., Ravenswood, Low Fell, Gateshead 380
1864		Marwick, Sir James David, LL.D., 19 Woodside Terrace, Glasgow
1885	C.	* Masson, Orme, D.Sc., F.R.S., Professor of Chemistry in the University of Melbourne
1898	C. B.	* Masterman, Arthur Thomas, M.A., D.Sc., Inspector of Fisheries, Board of Agriculture, Whitehall, London
1906		* Mathieson, Robert, F.C.S., Rillbank, Innerleithen
1902		Matthews, Ernest Romney, Assoc. Memb. Inst. C.E., F.G.S., Bessemer Prizeman, Soc. Engineers, Bridlington, Yorkshire 385
1901		* Menzies, Alan W. C., M.A., B.Sc., F.C.S., Professor of Chemistry in St Mungo's College, Glasgow
1888		Methven, Cathcart W., Memb. Inst. C.E., F.R.I.B.A., Durban, Natal, S. Africa
1902	C.	Metzler, William H., A.B., Ph.D., Corresponding Fellow of the Royal Society of Canada, Professor of Mathematics, Syracuse University, Syracuse, N.Y.
1885	C. B.	* Mill, Hugh Robert, D.Sc., LL.D., 62 Camden Square, London
1905		* Miller-Milne, C. H., M.A., Rector, The High School, Arbroath, 8 Dalhousie Place, Arbroath 390
1905		* Milne, Archibald, M.A., B.Sc., Lecturer on Mathematics and Science, Church of Scotland Training College, 5 Elgin Terrace
1904		* Milne, James Robert, D.Sc., 56 Manor Place
1886	C.	* Milne, William, M.A., B.Sc., 70 Beechgrove Terrace, Aberdeen
1899		* Milroy, T. H., M.D., B.Sc., Professor of Physiology in Queen's College, Belfast, Thomlea, Malone Park, Belfast
1866		Mitchell, Sir Arthur, K.C.B., M.A., M.D., LL.D., 34 Drummond Place 395
1889	C.	Mitchell, A. Crichton, D.Sc., Professor of Pure and Applied Mathematics, and Principal of the Maharajah's College, Trivandrum, Travancore, India
1897		* Mitchell, George Arthur, M.A., 9 Lowther Terrace, Kelvinside, Glasgow
1900		* Mitchell, James, M.A., B.Sc., 4 Manse Street, Kilmarnock
1899		* Mitchell-Thomson, Sir Mitchell, Bart., 6 Charlotte Square
1906	C.	Moffat, The Rev. Alexander, M.A., B.Sc., Professor of Physical Science, Christian College, Madras, India 400
1890	C.	Mond, R. L., M.A. Cantab., F.C.S., The Poplars, 20 Avenue Road, Regent's Park, London
1887	C.	Moos, N. A. F., L.C.E., B.Sc., Professor of Physics, Elphinstone College, and Director of the Government Observatory, Colaba, Bombay
1901		* More, James, jun., M. Inst. C.E., F.R.M.S.
1896		* Morgan, Alexander, M.A., D.Sc., Rector, Church of Scotland Training College, 1 Midmar Gardens

Date of Election.		
1892		Morrison, J. T., M.A., B.Sc., Professor of Physics and Chemistry, Victoria College, Stellenbosch, Cape Colony 405
1901		Moses, O. St John, M.D., B.Sc., F.R.C.S.E., Captain, Indian Medical Service, 8 Lansdowne Road, Calcutta, India
1892	C.	* Mossman, Robert C., Superintendent of Publications, Argentine Meteorological Office, Viamonte 640, Buenos Ayres
1874	C. K.	Muir, Thomas, C.M.G., M.A., LL.D., F.R.S., Superintendent-General of Education for Cape Colony, Education Office, Cape Town, and Mowbray Hall, Rosebank, Cape Colony
1888	C.	* Muirhead, George, Commissioner to His Grace the Duke of Richmond and Gordon, K.G., Speybank, Fochabers
1907		Muirhead, James M. P., Bredisholm, Claremont, near Cape Town, Cape Colony 410
1887		Mukhopâdhyay, Âsûtosh, M.A., LL.D., F.R.A.S., M.R.I.A., Professor of Mathematics at the Indian Association for the Cultivation of Science, 77 Russa Road North, Bhowanipore, Calcutta
1894		* Munro, J. M. M., Memb. Inst. E.E., 136 Bothwell Street, Glasgow
1891	C.	* Munro, Robert, M.A., M.D., LL.D., Hon. Memb. R.I.A., Hon. Memb. Royal Soc. of Antiquaries of Ireland (VICE-PRESIDENT), Elmbank, Largs, Ayrshire
1896		* Murray, Alfred A., M.A., LL.B., Westfield House, Cramond Bridge
1892	C.	* Murray, George Robert Milne, F.R.S., F.L.S., 8 Kerrison Road, Ealing, London 415
1907	C.	* Murray, James, Park Road, Maxwelltown, Dumfries
1877	C. B. N.	Murray, Sir John, K.C.B., LL.D., D.C.L., Ph.D., D.Sc., F.R.S., Member of the Prussian Order *Pour le Mérite*, Director of the Challenger Expedition Publications. Office, Villa Medusa, Boswell Road. House, Challenger Lodge, Wardie; and United Service Club
1907		* Musgrove, James, M.D., F.R.C.S. Edin. and Eng., Bute Professor of Anatomy, University of St Andrews, 56 South Street, St Andrews
1887		Muter, John, M.A., F.C.S., South London Central Public Laboratory, 325 Kennington Road, London
1902		Mylne, The Rev. R. S., M.A., B.C.L., Oxford, F.S.A. Lond., Great Amwell, Herts 420
1888		Napier, A. D. Leith, M.D., C.M., M.R.C.P.L., 28 Angas Street, Adelaide, S. Australia
1897		Nash, Alfred George, C.E., B.Sc., Engineer, Department of Public Works, Jamaica, Belretiro, Mandeville, Jamaica, W.I.
1887		* Nasmyth, T. Goodall, M.D., C.M., D.Sc., Cupar-Fife
1906		* Newington, Frank A., Memb. Inst. C.E., Memb. Inst. E.E., 4 Osborne Terrace
1898		Newman, George, M.D., D.P.H. Cambridge, Lecturer on Preventive Medicine, St Bartholomew's Hospital, University of London: Dene, Hatch End, Middlesex 425
1884		* Nicholson, J. Shield, M.A., D.Sc., Professor of Political Economy in the University of Edinburgh, 3 Belford Park
1880	C.	Nicol, W. W. J., M.A., D.Sc., 15 Blacket Place
1878		Norris, Richard, M.D., M.R.C.S. Eng., 3 Walsall Road, Birchfield, Birmingham
1902		Nunn, Colonel Joshua Arthur, C.I.E., D.S.O., F.R.C.V.S., Barrister-at-Law, Lincoln's Inn; Principal Veterinary Officer in India, Simla, India
1906		* O'Connor, Henry, C.E., Assoc. Memb. Inst. C.E., 1 Drummond Place 430
1888		* Ogilvie, F. Grant, C.B., M.A., B.Sc., Principal Assistant Secretary for Science, Art, and Technology, Board of Education, South Kensington, London
1888		* Oliphant, James, M.A., 11 Heathfield Park, Willesden, London

Date of Election.		
1886	C.	Oliver, James, M.D., F.L.S., Physician to the London Hospital for Women, 18 Gordon Square, London
1895	C.	Oliver, Thomas, M.D., F.R.C.P., Professor of Physiology in the University of Durham, 7 Ellison Place, Newcastle-upon-Tyne
1884	C. K.	* Omond, R. Traill, 3 Church Hill 435
1905		Pallin, William Alfred, F.R.C.V.S., Captain in the Army Veterinary Department, c/o Messrs Holt & Co., 3 Whitehall Place, London
1892		Parker, Thomas, Memb. Inst. C.E., 1B Chapel Street, Edgeware Road, London
1901		* Paterson, David, F.C.S., Lea Bank, Rosslyn, Midlothian
1886	C.	* Paton, D. Noël, M.D., B.Sc., F.R.C.P.E., Professor of Physiology in the University of Glasgow, University, Glasgow
1889		* Patrick, David, M.A., LL.D., c/o W. & R. Chambers, 339 High Street 440
1892		* Paulin, David, Actuary, 6 Forres Street
1881	C. N.	Peach, Benjamin N., LL.D., F.R.S., F.G.S., late District Superintendent and Acting Palæontologist of the Geological Survey of Scotland, 72 Grange Loan
1907		* Pearce, John Thomson, B.A., B.Sc., Principal Mathematical Lecturer, Leith Technical College, Leith Links, Leith
1904		* Peck, James Wallace, M.A., Principal Assistant to Executive Officer (Education) of the London County Council, Heath House, New End Square, Hampstead, London
1889		* Peck, William, F.R.A.S., Town's Astronomer, City Observatory, Calton Hill, Edinburgh 445
1887	C. B.	* Peddie, Wm., D.Sc., Professor of Natural Philosophy in University College, Dundee, Rosemount, Forthill Road, Broughty Ferry
1900		Penny, John, M.B., C.M., D.Sc., Great Broughton, near Cockermouth, Cumberland
1893		Perkin, Arthur George, F.R.S., 8 Montpellier Terrace, Hyde Park, Leeds
1889		* Philip, R. W., M.A., M.D., F.R.C.P.E., 45 Charlotte Square
1907		Phillips, Charles E. S., Castle Houses, Shooter's Hill, Kent 450
1905		* Pinkerton, Peter, M.A., Head Mathematical Master, George Watson's College, Edinburgh, 36 Morningside Grove
1906		Pitchford, Herbert Watkins, F.R.C.V.S., Bacteriologist and Analyst, Natal Government, The Laboratory, Pietermaritzburg, Natal
1886		Pollock, Charles Frederick, M.D., F.R.C.S.E., 1 Buckingham Terrace, Hillhead, Glasgow
1888		Prain, David, Lt.-Col., Indian Medical Service, M.A., M.B., LL.D., F.L.S., F.R.S., Hon. Memb. Soc. Lett. ed Arti d. Zelanti, Acireale; Corr. Memb. Pharm. Soc. Gt. Britain, etc.; Director, Royal Botanic Gardens, Kew (late Director, Botanical Survey of India, Calcutta), Botanic Gardens, Kew
1902		* Preller, Charles Du Riche, M.A., Ph.D., Assoc. Memb. Inst. C.E., 61 Melville Street 455
1892		* Pressland, Arthur J., M.A. Camb., Edinburgh Academy
1875	C.	Prevost, E. W., Ph.D., Weston, Ross, Herefordshire
1885		* Pullar, J. F., Rosebank, Perth
1903		* Pullar, Laurence, The Lea, Bridge of Allan
1880		Pullar, Sir Robert, LL.D., M.P. for the City of Perth, Tayside, Perth 460
1898		* Purves, John Archibald, D.Sc., 53 York Place
1897		* Rainy, Harry, M.B., C.M., F.R.C.P. Ed., 16 Great Stuart Street
1899		* Ramage, Alexander G., 8 Western Terrace, Murrayfield
1884		Ramsay, E. Peirson, M.R.I.A., F.L.S., C.M.Z.S., F.R.G.S., F.G.S., Fellow of the Imperial and Royal Zoological and Botanical Society of Vienna, Curator of Australian Museum, Sydney, N.S.W.

Date of Election.		
1891		* Rankine, John, M.A., LL.D., Advocate, Professor of the Law of Scotland in the University of Edinburgh, 23 Ainslie Place 465
1904		Ratcliffe, Joseph Riley, M.B., C.M., Elmdon, Wake Green Road, Morley, Birmingham
1900		Raw, Nathan, M.D., Mill Road Infirmary, Liverpool
1883	C.	Readman, J. B., D.Sc., F.C.S., Staffield Hall, Kirkoswald, R.S.O., Cumberland
1889		Redwood, Sir Boverton, D.Sc. (Hon.), F.I.C., F.C.S., Assoc. Inst. C.E., Wadham Lodge, Wadham Gardens, London
1902		Rees-Roberts, John Vernon, M.D., D.Sc., D.P.H., Barrister-at-Law, National Liberal Club, Whitehall Place, London 470
1902		Reid, George Archdall O'Brien, M.B., C.M., 9 Victoria Road South, Southsea, Hants
1875		Richardson, Ralph, W.S., 10 Magdala Place
1906	C.	* Ritchie, William Thomas, M.D., F.R.C.P.E., 9 Atholl Place
1898	C.	Roberts, Alexander William, D.Sc., F.R.A.S., Lovedale, South Africa
1880		Roberts, D. Lloyd, M.D., F.R.C.P.L., 23 St John Street, Manchester 475
1872		Robertson, D. M. C. L. Argyll, M.D., F.R.C.S.E., LL.D., Surgeon Oculist to the King in Scotland, Mon Plaisir, St Aubins, Jersey
1900		* Robertson, Joseph M'Gregor, M.B., C.M., 26 Buckingham Terrace, Glasgow
1896		* Robertson, Robert, M.A., 25 Mansionhouse Road
1902	C.	* Robertson, Robert A., M.A., B.Sc., Lecturer on Botany in the University of St Andrews
1896	C.	* Robertson, W. G. Aitchison, D.Sc., M.D., F.R.C.P.E., 26 Minto Street 480
1905	C.	* Romanes, George, C.E., Craigknowe, Slateford, Midlothian
1881		Rosebery, The Right Hon. the Earl of, K.G., K.T., LL.D., D.C.L., F.R.S., Dalmeny Park, Edinburgh
1880		Rowland, L. L., M.A., M.D., President of the Oregon State Medical Society, and Professor of Physiology and Microscopy in Williamette University, Salem, Oregon
1906		* Russell, Alexander Durie, B.Sc., Mathematical Master, Falkirk High School, Dunaura, Heugh Street, Falkirk
1902	C.	* Russell, James, 11 Argyll Place 485
1880		Russell, Sir James A., M.A., B.Sc., M.B., F.R.C.P.E., LL.D., Woodville, Canaan Lane
1904		Sachs, Edwin O., Architect, 7 Waterloo Place, Pall Mall, London, S.W.
1906		Saleeby, Caleb William, M.D., 13 Greville Place, London
1903		* Samuel, John S., 8 Park Avenue, Glasgow
1897		* Sanderson, William, Talbot House, Ferry Road 490
1903		* Sarolea, Charles, Ph.D., D. Litt., Lecturer on French Language, Literature, and Romance Philology, University of Edinburgh, 7 Merchiston Avenue
1895		Savage, Thomas, M.D., F.R.C.S. England, M.R.C.P. London, Professor of Gynæcology, Mason College, Birmingham, The Ards, Knowle, Warwickshire
1891		Sawyer, Sir James, Knt., M.D., F.R.C.P., F.S.A., J.P., Consulting Physician to the Queen's Hospital, 31 Temple Row, Birmingham
1900	C.	* Schäfer, Edward Albert, M.R.C.S., LL.D., F.R.S., Professor of Physiology in the University of Edinburgh
1885	C.	Scott, Alexander, M.A., D.Sc., F.R.S., The Davy-Faraday Research Laboratory of the Royal Institution, London 495
1880		Scott, J. H., M.B., C.M., M.R.C.S., Prof. of Anatomy in the University of Otago, New Zealand
1905		Scougal, A. E., M.A., H.M.C.I.S., 1 Wester Coates Avenue

Date of Election.		
1902		Senn, Nicholas, M.D., LL.D., Professor of Surgery, Rush Medical College, Chicago, U.S.A.
1872	C.	Seton, George, M.A., Advocate, Ayton House, Abernethy, Perthshire
1897		* Shepherd, John William, Carrickarden, Bearsden, Glasgow 500
1894		* Shield, Wm., Memb. Inst. C.E., 33 Old Queen Street, Westminster, London
1871		Simpson, Sir A. R., M.D., Emeritus Professor of Midwifery in the University of Edinburgh, 52 Queen Street
1900	C.	* Simpson, James Young, M.A., D.Sc., Professor of Natural Science in the New College, Edinburgh, 52 Queen Street
1903		* Skinner, Robert Taylor, M.A., Governor and Head Master, Donaldson's Hospital, Edinburgh
1901		* Smart, Edward, B.A., B.Sc., Benview, Craigie, Perth 505
1891	C.	* Smith, Alexander, B.Sc., Ph.D., Professor of General Chemistry, University of Chicago, Ills., U.S.
1882	C.	Smith, C. Michie, B.Sc., F.R.A.S., Director of the Kodaikánal and Madras Observatories, The Observatory, Kodaikánal, South India
1885		* Smith, George, F.C.S., Polmont Station
1871	C.	Smith, John, M.D., F.R.C.S.E., LL.D., 11 Wemyss Place
1904		* Smith, William Charles, K.C., M.A., LL.B., Advocate, 6 Darnaway Street 510
1907	C.	Smith, William Ramsay, D.Sc., M.B., C.M., Permanent Head of the Health Department, South Australia, Winchester Street, East Adelaide, South Australia
1880		Smith, William Robert, M.D., D.Sc., Barrister-at-Law, Professor of Forensic Medicine in King's College, 74 Great Russell Street, Bloomsbury Square, London
1899		Snell, Ernest Hugh, M.D., B.Sc., D.P.H. Camb., Coventry
1880		Sollas, W. J., M.A., D.Sc., LL.D., F.R.S., late Fellow of St John's College, Cambridge, and Professor of Geology and Palæontology in the University of Oxford
1889	C	Somerville, Wm., M.A., D.Sc., D.Oec., Sibthorpian Professor of Rural Economy in the University of Oxford, 121 Banbury Road, Oxford 515
1882		Sorley, James, F.I.A., C.A., 82 Onslow Gardens, London
1896		* Spence, Frank, M.A., B.Sc., 25 Craiglea Drive
1874	C.	Sprague, T. B., M.A., LL.D., Actuary, 29 Buckingham Terrace
1906		Squance, Thomas Coke, M.D., Physician and Pathologist in the Sunderland Infirmary, 15 Grange Crescent, Sunderland
1891		* Stanfield, Richard, Professor of Mechanics and Engineering in the Heriot-Watt College 520
1886	C.	* Stevenson, Charles A., B.Sc., Memb. Inst. C.E., 28 Douglas Crescent
1884		* Stevenson, David Alan, B.Sc., Memb. Inst. C.E., 45 Melville Street
1868		Stevenson, John J., 4 Porchester Gardens, London
1888	C.	* Stewart, Charles Hunter, D.Sc., M.B., C.M., Professor of Public Health in the University of Edinburgh, 9 Learmonth Gardens
1868		Stewart, Major-General J. H. M. Shaw, late R.E., Assoc. Inst. C.E., F.R.G.S., 7 Inverness Terrace, London, W. 525
1904		* Stewart, Thomas W., M.A., B.Sc., Science Master, Edinburgh Ladies' College, 29 Bruntsfield Gardens
1873		Stewart, Walter, 3 Queensferry Gardens
1877		Stirling, William, D.Sc., M.D., LL.D., Brackenbury Professor of Physiology and Histology in Owens College and Victoria University, Manchester
1902		* Stockdale, Herbert Fitton, Clairinch, Upper Helensburgh, Dumbartonshire

Date of Election		
1889	C.	* Stockman, Ralph, M.D., F.R.C.P.E., Professor of Materia Medica and Therapeutics in the University of Glasgow 530
1906		Story, Fraser, Lecturer in Forestry, University College, Nottingham
1907		* Strong, John, B.A., Rector of Montrose Academy, 11 Union Place, Montrose
1903		Sutherland, David W., M.D., M.R.C.P. Lond., Captain, Indian Medical Service, Professor of Pathology and Materia Medica, Medical College, Lahore, India
1896		* Sutherland, John Francis, M.D., Dep. Com. in Lunacy for Scotland, Scotsburn Road, Tain, Ross-shire
1905		Swithinbank, Harold William, Denham Court, Denham, Bucks 535
1885	C.	* Symington, Johnson, M.D., F.R.C.S.E., F.R.S., Prof. of Anatomy in Queen's College, Belfast
1904		* Tait, John W., B.Sc., Rector of Leith Academy, 18 Netherby Road, Leith
1898	C.	Tait, William Archer, B.Sc., Memb. Inst. C.E., 38 George Square
1895		Talmage, James Edward, D.Sc., Ph.D., F.R.M.S., F.G.S., Professor of Geology, Univ. of Utah, Salt Lake City, Utah
1890	C.	Tanakadate, Aikitu, Professor of Natural Philosophy in the Imperial University of Japan, Tokyo, Japan 540
1870		Tatlock, Robert R., F.C.S., City Analyst's Office, 156 Bath Street, Glasgow
1899		* Taylor, James, M.A., Mathematical Master in the Edinburgh Academy, Edinburgh Academy
1892	C.	Thackwell, J. B., M.B., C.M.
1885		* Thompson, D'Arcy W., C.B., B.A., F.L.S., Professor of Natural History in University College, Dundee
1907		* Thompson, John Hannay, M. Inst. C.E., M. Inst. Mech. E., Engineer to the Dundee Harbour Trust, Earlville, Broughty Ferry 545
1905		* Thoms, Alexander, 7 Playfair Terrace, St Andrews
1887		* Thomson, Andrew, M.A., D.Sc., F.I.C., Rector, Perth Academy, Ardenlea, Pitcullen, Perth
1896		* Thomson, George Ritchie, M.B., C.M., Cumberland House, Von Brandis Square, Johannesburg, Transvaal
1903		Thomson, George S., F.C.S., Dairy Commissioner for Queensland, Department of Agriculture, Brisbane, Queensland
1906		* Thomson, Gilbert, C.E., 164 Bath Street, Glasgow 550
1887	C.	* Thomson, J. Arthur, M.A., Regius Prof. of Natural History in the Univ. of Aberdeen
1906		Thomson, James Stuart, F.L.S., Assistant Professor of Zoology, South, African College, Cape Town, Worcester House, Worcester Road, Sea Point, Cape Town, S.A.
1880		Thomson, John Millar, LL.D., F.R.S., Professor of Chemistry in King's College, Lond., 9 Campden Hill Gardens, London
1899		* Thomson, R. Tatlock, F.C.S., 156 Bath Street, Glasgow
1870		Thomson, Spencer C., Actuary, 10 Eglinton Crescent 555
1882		Thomson, Wm., M.A., B.Sc., LL.D., Registrar, University of the Cape of Good Hope, University Buildings, Cape Town
1876		Thomson, William, Royal Institution, Manchester
1874	C. B. N.	Traquair, R. H., M.D., LL.D., F.R.S., F.G.S., late Keeper of the Natural History Collections in the Royal Scottish Museum, Edinburgh (VICE-PRESIDENT), The Bush, Colinton
1874		Tuke, Sir J. Batty, M.D., D.Sc., LL.D., F.R.C.P.E., M.P. for the Universities of Edinburgh and St Andrews, 20 Charlotte Square
1888		* Turnbull, Andrew H., Actuary, The Elms, Whitehouse Loan 560

Date of Election.		
1905		* Turner, Arthur Logan, M.D., F.R.C.S.E., 27 Walker Street
1906		* Turner, Dawson F. D., B.A., M.D., F.R.C.P.E., M.R.C.P. Lond., Lecturer on Physics, Surgeon's Hall, and Physician in charge of Electrical Department, Royal Infirmary, Edinburgh, 37 George Square
1861	K. N. C.	Turner, Sir William, K.C.B., M.B., F.R.C.S.E., LL.D., D.C.L., D.Sc. Dub., F.R.S., Principal of the University of Edinburgh, 6 Eton Terrace
1895		Turton, Albert H., M.I.M.M., 18 Harrow Road, Bowenbrook, Birmingham
1898	C.	* Tweedie, Charles, M.A., B.Sc., Lecturer on Mathematics in the University of Edinburgh, 40 Gillespie Crescent 565
1877		Underhill, Charles E., B.A., M.B., F.R.C.P.E., F.R.C.S.E., 8 Coates Crescent
1889		Underhill, T. Edgar, M.D., F.R.C.S.E., Dunedin, Barnt Green, Worcestershire
1906		Vandenbergh, William J., Barrister-at-Law, S.S.C., F.R.S.L., F.R.M.S., 29–32 Exchange Buildings, Pirie Street, Adelaide, S. Australia
1888		Walker, James, Memb. Inst. C.E., Engineer's Office, Tyne Improvement Commission, Newcastle-on-Tyne
1891	C. B.	* Walker, James, D.Sc., Ph.D., F.R.S., Professor of Chemistry in University College, Dundee, 8 Windsor Terrace, Dundee 570
1873	C.	Walker, Robert, M.A., LL.D., University, Aberdeen
1902		* Wallace, Alexander G., M.A., 154 Forrest Avenue, Aberdeen
1886	C.	* Wallace, R., F.L.S., Prof. of Agriculture and Rural Economy in the Univ. of Edin.
1898		Wallace, Wm., M.A., Belvedere, Alta, Canada
1891		* Walmsley, R. Mullineux, D.Sc., Prin. of the Northampton Inst., Clerkenwell, London 575
1907		Waters, E. Wynston, Medical Officer, H.B.M. Administration, E. Africa, Lamu, British East Africa Protectorate, *via* Mombasa
1901	C.	* Waterston, David, M.A., M.D., F.R.C.S.E., Lecturer on Regional Anatomy in the University of Edinburgh, 15 Greenhill Gardens
1904		* Watson, Charles B. Boog, Huntly Lodge, 1 Napier Road
1866		Watson, Sir Patrick Heron, M.D., LL.D., F.R.C.S.E. and I., Surgeon in Ordinary to the King in Scotland, 16 Charlotte Square
1862	C.	Watson, Rev. Robert Boog, B.A., LL.D., F.L.S., Past President of the Conchological Society, 11 Strathearn Place 580
1900		* Watson, Thomas P., M.A., B.Sc., Principal, Keighley Institute, Keighley
1907		* Watt, Andrew, M.A., Secretary to the Scottish Meteorological Society, 6 Woodburn Terrace
1896		Webster, John Clarence, B.A., M.D., F.R.C.P.E., Professor of Obstetrics and Gynæcology, Rush Medical College, Chicago, 706 Reliance Buildings, 100 State Street, Chicago
1907	C.	* Wedderburn, Ernest Maclagan, M.A., LL.B., 6 Succoth Gardens
1903	C.	* Wedderburn, J. H. Maclagan, M.A., Lecturer on Mathematics in the University of Edinburgh, 6 Succoth Gardens 585
1904		Wedderspoon, William Gibson, M.A., LL.D., Indian Educational Service, Senior Inspector of Schools, Burma, The Education Office, Rangoon, Burma
1896		Wenley, R. M., M.A., D.Sc., D.Phil., LL.D., Prof. of Philosophy in the University of Michigan, U.S.
1896	C.	White, Philip J., M.B., Prof. of Zoology in University College, Bangor, North Wales
1890		White, Sir William Henry, K.C.B., Memb. Inst. C.E., LL.D., F.R.S., late Assistant Controller of the Navy, and Director of Naval Construction, Cedarscroft, Putney Heath, London

Date of Election.		
1881		Whitehead, Walter, F.R.C.S.E., Late Professor of Clinical Surgery, Owens College and Victoria University, Birchfield, Rusholme, Manchester 590
1894		Whymper, Edward, F.R.G.S., Holmwood, Waldegrave Road, Teddington, Middlesex
1879		Will, John Charles Ogilvie, of Newton of Pitfodels, M.D., 17 Bon-Accord Square, Aberdeen
1897		* Williams, W. Owen, F.R.C.V.S., Professor of Veterinary Medicine and Surgery, University of Liverpool, The Veterinary School, The University, Liverpool
1900		Wilson, Alfred C., F.C.S., Voewood Croft, Stockton-on-Tees
1879		Wilson, Andrew, Ph.D., F.L.S., Lecturer on Zoology and Comparative Anatomy, 110 Gilmore Place 595
1902		* Wilson, Charles T. R., M.A., F.R.S., Glencorse House, Peebles, and Sidney Sussex College, Cambridge
1895		Wilson-Barker, David, F.R.G.S., Captain-Superintendent Thames Nautical Training College, H.M.S. "Worcester," Greenhithe, Kent
1882		Wilson, George, M.A., M.D., LL.D., 7 Avon Place, Warwick
1891		* Wilson, John Hardie, D.Sc., University of St Andrews, 39 South Street, St Andrews
1902		Wilson, William Wright, F.R.C.S.E., M.R.C.S. Eng., Cottesbrook House, Acock's Green, Birmingham 600
1886	C.	* Woodhead, German Sims, M.D., F.R.C.P.E., Prof. of Pathology in the University of Cambridge
1884		Woods, G. A., M.R.C.S., Eversleigh, 1 Newstead Road, Lee, Kent
1890		* Wright, Johnstone Christie, Northfield, Colinton
1896		* Wright, Robert Patrick, Professor of Agriculture, West of Scotland Agricultural College, 6 Blythswood Square, Glasgow
1882		Young, Frank W., F.C.S., H.M. Inspector of Science and Art Schools, 32 Buckingham Terrace, Botanic Gardens, Glasgow 605
1892		Young, George, Ph.D., 79 Harvard Court Mansions, Honeybourne Road, West Hampstead, London, N.W.
1896	C.	* Young, James Buchanan, M.B., D.Sc., Dalveen, Braeside, Liberton
1900		* Young, J. M'Lauchlan, F.R.C.V.S., Lecturer on Veterinary Hygiene, University of Aberdeen
1904		Young, R. B., M.A., B.Sc., Transvaal Technical Institute, Johannesburg, Transvaal

I

Elected	
1897	Alexander
1897	E.-H. Amag
1900	Arthur Auv
1900	Adolf Ritte
1905	Waldemar C
1897	Stanislao C
1905	Moritz Cant
1902	Jean Gaston
1902	Anton Dohr
1905	Paul Ehrlic
1902	Albert Gaud
1905	Paul Heinri
1888	Ernst Haecl
1883	Julius Hann
1879	Jules Janss
1897	Gabriel Lip
1895	Éleuthère-É
1895	Carl Menge
1897	Fridtjof Na
1881	Simon New
1905	Eduard Pflü
1895	Jules Henri
1889	Georg Hern
1897	Giovanni V.
1905	Eduard Sue
1905	Wilhelm W
1905	Wilhelm W
1897	Ferdinand Z

Total, 28.

BRITISH SUBJECTS (LIMITED TO TWENTY BY LAW X.).

Elected		
1889	Sir Robert Stawell Ball, Kt., LL.D., F.R.S., M.R.I.A., Lowndean Professor of Astronomy in the University of Cambridge,	*Cambridge.*
1900	Edward Caird, LL.D., Master of Balliol College, Oxford,	*Oxford.*
1892	Colonel Alexander Ross Clarke, C.B., R.E., F.R.S.,	*Redhill, Surrey.*
1897	Sir George Howard Darwin, K.C.B., M.A., LL.D., F.R.S., Plumian Professor of Astronomy in the University of Cambridge,	*Cambridge.*
1900	David Ferrier, M.D., LL.D., F.R.S., Prof. of Neuro-pathology, King's College, London,	*London.*
1900	Andrew Russell Forsyth, D.Sc., F.R.S., Sadlerian Professor of Pure Mathematics in the University of Cambridge,	*Cambridge.*
1892	Sir David Gill, K.C.B., LL.D., F.R.S., formerly His Majesty's Astronomer at the Cape of Good Hope,	*London*
1895	Albert C. L. G. Günther, Ph.D., F.R.S.,	*London.*
1883	Sir Joseph Dalton Hooker, K.C.S.I., M.D., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1884	Sir William Huggins, K.C.B., LL.D., D.C.L., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1900	Archibald Liversidge, LL.D., F.R.S., Professor of Chemistry in the University of Sydney,	*Sydney.*
1905	Sir William Ramsay, K.C.B., LL.D., F.R.S., Professor of Chemistry in the University College, London,	*London.*
1886	The Lord Rayleigh, D.C.L., LL.D., D.Sc. Dub., F.R.S., Corresp. Mem. Inst. of France,	*London.*
1905	Joseph John Thomson, D.Sc., LL.D., F.R.S., Cavendish Professor of Experimental Physics, University of Cambridge,	*Cambridge.*
1900	Thomas Edward Thorpe, D.Sc., LL.D., F.R.S., Principal of the Government Laboratories, London,	*London.*
1895	Sir Charles Todd, K.C.M.G., F.R.S., Government Astronomer, South Australia,	*Adelaide.*

Total 16.

ORDINARY FELLOWS ELECTED

During Session 1905–1906.

Arranged according to the Date of their Election.

20th November 1905.

Robert Mathieson, F.C.S.

18th December 1905.

William Spiers Bruce.
Thomas James Jehu, M.A., M.D., F.G.S.
William Thomas Ritchie, M.D., F.R.C.P.
Alexander Durie Russell, B.Sc.

22nd January 1906.

Henry O'Connor, C.E.
Fraser Story.
Gilbert Thomson, M.A., C.E.
Dawson F. D. Turner, B.A., M.D., F.R.C.P.I.
Robert Alex. Fleming, M.D., F.R.C.P.E.
The Rev. Samuel Johnston, B.A., D.Sc.
Duncan Scott Macnair, Ph.D., H.M.I.S.

19th February 1906.

Lt.-Col. Arthur Fred. Appleton, F.R.C.V.S.
Thomas William Dewar, M.D., F.R.C.P.E.
The Rev. Alex. Moffat, M.A., B.Sc.
Herbert Watkins Pitchford, F.R.C.V.S.
Caleb Williams Saleeby, M.D.

19th March 1906.

Prof. Frank Watson Dyson, M.A. F.R.S.
Alexander Taylor Innes, M.A.
John Patrick Tait Bell, F.Z.S.
Edward David Wilson Greig, M.D., B.S.
Captain I.M.S.
Thomas Coke Squance, M.D.
James Stuart Thomson, F.L.S.

4th June 1906.

Frank A. Newington, Memb. Inst. C.E.
William J. Vandenbergh, S.S.C.
Daniel E. Anderson, M.D., B.A., B.Sc.

18th June 1906.

David Ellis, D.Sc., Ph.D.

ORDINARY FELLOWS DECEASED OR RESIGNED

During Session 1905–1906.

DECEASED.

Professor James Blyth, M.A., LL.D.
A. B. Brown, C.E., Memb. Inst. Mech. E.
William A. Bryson.
George H. Geddes.
William Gilmour.
Richard John Lloyd, M.A., D.Lit.
Philip R. D. Maclagan, F.F.A.
The Rev. George Matheson, M.A., D.D., LL.D.
Major F. Ignacio Ricarde-Seaver.
The Right Rev. Bishop D. F. Sandford, D.D., LL.D.

RESIGNED.

A. J. Herbertson.

HONORARY FELLOWS DECEASED

During Session 1905–1906.

FOREIGN.

Ludwig Boltzmann.
Albert von Kölliker.
Samuel Pierpont Langley.

BRITISH.

Sir Richard C. Jebb.
Sir J. S. Burdon Sanderson, Bart.

ORDINARY FELLOWS ELECTED

During Session 1906–1907.

Arranged according to the Date of their Election.

19th November 1906.

Charles E. S. Phillips. Edward Oswald Fergus.
Edwin Bramwell, M.B., F.R.C.P.E.

17th December 1906.

Donald Alexander MacAlister, F.G.S. William Ramsay Smith, D.Sc., M.B., C.M.

21st January 1907.

Peter Macnair. Professor James Musgrove, M.D., F.R.C.S.E.
James M. P. Muirhead. E. Wynston Waters.
Ernest Maclagan Wedderburn, M.A., LL.B.

18th February 1907.

William Cramer, Ph.D. Gilbert Henry Gulliver.
John Downie Falconer, M.A., D.Sc. John Strong, B.A.
Andrew Watt, M.A.

18th March 1907.

John Anderson Gilruth, M.R.C.V.S. William Robertson.

20th May 1907.

Frederick Alexander Black. John Kemp, M.A.
Professor Alexander Brown, M.A., B.Sc. John Hannay Thompson, Memb. Inst. C.E

24th June 1907.

James Archibald, M.A. William Forster Lanchester, M.A.
Muhammad Badre.

15th July 1907.

Alexander Galbraith. James Knight, M.A., D.Sc.
Archibald King, M.A., B.Sc. James Murray.
John Thomson Pearce, B.A., B.Sc.

ORDINARY FELLOWS DECEASED OR RESIGNED

During Session 1906–1907.

DECEASED.

Thomas Andrews, Memb. Inst. C.E., F.R.S.
Henry Bellyse Baildon, M.A., Ph.D.
John Richard Brittle, Memb. Inst. C.E.
Alexander Buchan, M.A., LL.D., F.R.S.
John Archibald Campbell, M.D.
Hugh Davidson.
Sir Joseph Fayrer, Bart., K.C.S.I., M.D.
Colonel Sir Charles Hughes-Hunter, Bart.
Professor David Masson, LL.D., Litt.D.
Alexander Peddie, M.D., F.R.C P.E.
James Sime, M.A.

RESIGNED.

Rev. Dugald Butler.

HONORARY FELLOWS DECEASED

During Session 1906–1907.

BRITISH.

Sir Benjamin Baker.
Professor Alfred Newton.

LAWS

OF THE

ROYAL SOCIETY OF EDINBURGH.

AS REVISED 18TH JULY 1904.

LAWS.

[By the Charter of the Society (printed in the *Transactions*, Vol. VI. p. 5), the Laws cannot be altered, except at a Meeting held one month after that at which the Motion for alteration shall have been proposed.]

I.

THE ROYAL SOCIETY OF EDINBURGH shall consist of Ordinary and Honorary Fellows. Title.

II.

Every Ordinary Fellow, within three months after his election, shall pay Two Guineas as the fee of admission, and Three Guineas as his contribution for the Session in which he has been elected; and annually at the commencement of every Session, Three Guineas into the hands of the Treasurer. This annual contribution shall continue for ten years after his admission, and it shall be limited to Two Guineas for fifteen years thereafter.* Fellows may compound for these contributions on such terms as the Council may from time to time fix. The fees of Ordinary Fellows residing in Scotland.

III.

All Fellows who shall have paid Twenty-five years' annual contribution shall be exempted from further payment. Payment to cease after 25 years.

IV.

The fees of admission of an Ordinary Non-Resident Fellow shall be £26, 5s., payable on his admission; and in case of any Non-Resident Fellow coming to reside at any time in Scotland, he shall, during each year of his residence, pay the usual annual contribution of £3, 3s., payable by each Resident Fellow; but after payment of such annual contribution for eight years, he shall be exempt Fees of Non-Resident Ordinary Fellows.

* A modification of this rule, in certain cases, was agreed to at a Meeting of the Society held on the 3rd January 1831.

At the Meeting of the Society, on the 5th January 1857, when the reduction of the Contributions from £3, 3s. to £2, 2s., from the 11th to the 25th year of membership, was adopted, it was resolved that the existing Members shall share in this reduction, so far as regards their future annual Contributions.

Case of Fellows becoming Non-Resident.

from any further payment. In the case of any Resident Fellow ceasing to reside in Scotland, and wishing to continue a Fellow of the Society, it shall be in the power of the Council to determine on what terms, in the circumstances of each case, the privilege of remaining a Fellow of the Society shall be continued to such Fellow while out of Scotland.

V.

Defaulters.

Members failing to pay their contributions for three successive years (due application having been made to them by the Treasurer) shall be reported to the Council, and, if they see fit, shall be declared from that period to be no longer Fellows, and the legal means for recovering such arrears shall be employed.

VI.

Privileges of Ordinary Fellows.

None but Ordinary Fellows shall bear any office in the Society, or vote in the choice of Fellows or Office-Bearers, or interfere in the patrimonial interests of the Society.

VII.

Numbers Unlimited.

The number of Ordinary Fellows shall be unlimited.

VIII.

Fellows entitled to Transactions.

The Ordinary Fellows, upon producing an order from the TREASURER, shall be entitled to receive from the Publisher, gratis, the Parts of the Society's Transactions which shall be published subsequent to their admission.

IX.

Mode of Recommending Ordinary Fellows.

Candidates for admission as Ordinary Fellows shall make an application in writing, and shall produce along with it a certificate of recommendation to the purport below,* signed by at least *four* Ordinary Fellows, two of whom shall certify their recommendation from personal knowledge. This recommendation shall be delivered to the Secretary, and by him laid before the Council, and shall be exhibited publicly in the Society's Rooms for one month, after which it shall be considered by the Council. If the Candidate be approved by the Council, notice of the day fixed for the election shall be given in the circulars of at least two Ordinary Meetings of the Society.

* "A. B., a gentleman well versed in Science (*or Polite Literature, as the case may be*), being "to our knowledge desirous of becoming a Fellow of the Royal Society of Edinburgh, we hereby "recommend him as deserving of that honour, and as likely to prove a useful and valuable Member."

X.

Honorary Fellows shall not be subject to any contribution. This class shall consist of persons eminently distinguished for science or literature. Its number shall not exceed Fifty-six, of whom Twenty may be British subjects, and Thirty-six may be subjects of foreign states. Honorary Fellows, British and Foreign.

XI.

Personages of Royal Blood may be elected Honorary Fellows, without regard to the limitation of numbers specified in Law X. Royal Personages.

XII.

Honorary Fellows may be proposed by the Council, or by a recommendation (in the form given below*) subscribed by three Ordinary Fellows; and in case the Council shall decline to bring this recommendation before the Society, it shall be competent for the proposers to bring the same before a General Meeting. The election shall be by ballot, after the proposal has been communicated *viva voce* from the Chair at one meeting, and printed in the circulars for two Ordinary Meetings of the Society, previous to the day of election. Recommendation of Honorary Fellows. Mode of Election.

XIII.

The election of Ordinary Fellows shall take place only at one Afternoon Ordinary Meeting of each month during the Session. The election shall be by ballot, and shall be determined by a majority of at least two-thirds of the votes, provided Twenty-four Fellows be present and vote. Election of Ordinary Fellows.

XIV.

The Ordinary Meetings shall be held on the first and third Mondays of each month from November to March, and from May to July, inclusive; with the exception that when there are five Mondays in January, the Meetings for that month shall be held on its second and fourth Mondays. Regular Minutes shall be kept of the proceedings, and the Secretaries shall do the duty alternately, or according to such agreement as they may find it convenient to make. Ordinary Meetings.

* We hereby recommend_____
for the distinction of being made an Honorary Fellow of this Society, declaring that each of us from our own knowledge of his services to (*Literature or Science, as the case may be*) believe him to be worthy of that honour.

(To be signed by three Ordinary Fellows.)

_____

_____

_____

To the President and Council of the Royal Society of Edinburgh.

XV.

The Transactions.

The Society shall from time to time publish its Transactions and Proceedings. For this purpose the Council shall select and arrange the papers which they shall deem it expedient to publish in the *Transactions* of the Society, and shall superintend the printing of the same.

The Council shall have power to regulate the private business of the Society. At any Meeting of the Council the Chairman shall have a casting as well as a deliberative vote.

XVI.

How Published.

The Transactions shall be published in parts or *Fasciculi* at the close of each Session, and the expense shall be defrayed by the Society.

XVII.

The Council.

That there shall be formed a Council, consisting—First, of such gentlemen as may have filled the office of President; and Secondly, of the following to be annually elected, viz.:—a President, Six Vice-Presidents (two at least of whom shall be resident), Twelve Ordinary Fellows as Councillors, a General Secretary, Two Secretaries to the Ordinary Meetings, a Treasurer, and a Curator of the Museum and Library.

XVIII.

Retiring Councillors.

Four Councillors shall go out annually, to be taken according to the order in which they stand on the list of the Council.

XIX.

Election of Office-Bearers.

An Extraordinary Meeting for the election of Office-Bearers shall be held annually on the fourth Monday of October, or on such other lawful day in October as the Council may fix, and each Session of the Society shall be held to begin at the date of the said Extraordinary Meeting.

XX.

Special Meetings; how called.

Special Meetings of the Society may be called by the Secretary, by direction of the Council; or on a requisition signed by six or more Ordinary Fellows. Notice of not less than two days must be given of such Meetings.

XXI.

Treasurer's Duties.

The Treasurer shall receive and disburse the money belonging to the Society, granting the necessary receipts, and collecting the money when due.

He shall keep regular accounts of all the cash received and expended, which shall be made up and balanced annually; and at the Extraordinary Meeting in October, he shall present the accounts for the preceding year, duly audited.

At this Meeting, the Treasurer shall also lay before the Council a list of all arrears due above two years, and the Council shall thereupon give such directions as they may deem necessary for recovery thereof.

XXII.

Auditor.

At the Extraordinary Meeting in October, a professional accountant shall be chosen to audit the Treasurer's accounts for that year, and to give the necessary discharge of his intromissions.

XXIII.

General Secretary's Duties.

The General Secretary shall keep Minutes of the Extraordinary Meetings of the Society, and of the Meetings of the Council, in two distinct books. He shall, under the direction of the Council, conduct the correspondence of the Society, and superintend its publications. For these purposes he shall, when necessary, employ a clerk, to be paid by the Society.

XXIV.

Secretaries to Ordinary Meetings.

The Secretaries to the Ordinary Meetings shall keep a regular Minute-book, in which a full account of the proceedings of these Meetings shall be entered; they shall specify all the Donations received, and furnish a list of them, and of the Donors' names, to the Curator of the Library and Museum; they shall likewise furnish the Treasurer with notes of all admissions of Ordinary Fellows. They shall assist the General Secretary in superintending the publications, and in his absence shall take his duty.

XXV.

Curator of Museum and Library.

The Curator of the Museum and Library shall have the custody and charge of all the Books, Manuscripts, objects of Natural History, Scientific Productions, and other articles of a similar description belonging to the Society; he shall take an account of these when received, and keep a regular catalogue of the whole, which shall lie in the Hall, for the inspection of the Fellows.

XXVI.

Use of Museum and Library.

All Articles of the above description shall be open to the inspection of the Fellows at the Hall of the Society, at such times and under such regulations as the Council from time to time shall appoint.

XXVII.

Register Book.

A Register shall be kept, in which the names of the Fellows shall be enrolled at their admission, with the date.

XXVIII.

Power of Expulsion.

If, in the opinion of the Council of the Society, the conduct of any Fellow is unbecoming the position of a Member of a learned Society, or is injurious to the character and interests of this Society, the Council may request such Fellow to resign; and, if he fail to do so within one month of such request being addressed to him, the Council shall call a General Meeting of the Fellows of the Society to consider the matter; and, if a majority of the Fellows present at such Meeting agree to the expulsion of such Member, he shall be then and there expelled by the declaration of the Chairman of the said Meeting to that effect; and he shall thereafter cease to be a Fellow of the Society, and his name shall be erased from the Roll of Fellows, and he shall forfeit all right or claim in or to the property of the Society.

THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES.

The above Prizes will be awarded by the Council in the following manner:—

I. KEITH PRIZE.

The KEITH PRIZE, consisting of a Gold Medal and from £40 to £50 in Money, will be awarded in the Session 1907–1908 for the "best communication on a scientific subject, communicated, in the first instance, to the Royal Society during the Sessions 1905–06 and 1906–07." Preference will be given to a paper containing a discovery.

II. MAKDOUGALL-BRISBANE PRIZE.

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded at the commencement of the Session 1908–1909, for an Essay or Paper having reference to any branch of scientific inquiry, whether Material or Mental.

2. Competing Essays to be addressed to the Secretary of the Society, and transmitted not later than 8th July 1908.

3. The Competition is open to all men of science.

4. The Essays may be either anonymous or otherwise. In the former case, they must be distinguished by mottoes, with corresponding sealed billets, superscribed with the same motto, and containing the name of the Author.

5. The Council impose no restriction as to the length of the Essays, which may be, at the discretion of the Council, read at the Ordinary Meetings of the Society. They wish also to leave the property and free disposal of the manuscripts to the Authors; a copy, however, being deposited in the Archives of the Society, unless the paper shall be published in the Transactions.

6. In awarding the Prize, the Council will also take into consideration any scientific papers presented to the Society during the Sessions 1906–07, 1907–08, whether they may have been given in with a view to the prize or not.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr PATRICK NEILL of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate,

1. The NEILL PRIZE, consisting of a Gold Medal and a sum of Money, will be awarded during the Session 1907–1908.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented to the Society during the three years preceding the 8th July 1907,—or failing presentation of a paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award.

IV. GUNNING VICTORIA JUBILEE PRIZE.

This Prize, founded in the year 1887 by Dr R. H. GUNNING, is to be awarded quadrennially by the Council of the Royal Society of Edinburgh, in recognition of original work in Physics, Chemistry, or Pure or Applied Mathematics.

Evidence of such work may be afforded either by a Paper presented to the Society, or by a Paper on one of the above subjects, or some discovery in them elsewhere communicated or made, which the Council may consider to be deserving of the Prize.

The Prize consists of a sum of money, and is open to men of science resident in or connected with Scotland. The first award was made in the year 1887.

In accordance with the wish of the Donor, the Council of the Society may on fit occasions award the Prize for work of a definite kind to be undertaken during the three succeeding years by a scientific man of recognised ability.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, NEILL, AND GUNNING VICTORIA JUBILEE PRIZES, FROM 1827 TO 1906.

I. KEITH PRIZE.

1st Biennial Period, 1827–29.—Dr Brewster, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2nd Biennial Period, 1829–31.—Dr Brewster, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3rd Biennial Period, 1831–33.—Thomas Graham, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4th Biennial Period, 1833–35.—Professor J. D. Forbes, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5th Biennial Period, 1835–37.—John Scott Russell, Esq., for his Researches "on Hydrodynamics," published in the Transactions of the Society.

6th Biennial Period, 1837–39.—Mr John Shaw, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7th Biennial Period, 1839–41.—Not awarded.

8th Biennial Period, 1841–43.—Professor James David Forbes, for his papers "on Glaciers," published in the Proceedings of the Society.

9th Biennial Period, 1843–45.—Not awarded.

10th Biennial Period, 1845–47.—General Sir Thomas Brisbane, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11th Biennial Period, 1847–49.—Not awarded.

12th Biennial Period, 1849–51.—Professor Kelland, for his papers "on General Differentiation, including his more recent Communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13th Biennial Period, 1851–53.—W. J. Macquorn Rankine, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14th Biennial Period, 1853–55.—Dr Thomas Anderson, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15th Biennial Period, 1855–57.—Professor Boole, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society

16TH BIENNIAL PERIOD, 1857–59.—Not awarded.

17TH BIENNIAL PERIOD, 1859–61.—JOHN ALLAN BROUN, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18TH BIENNIAL PERIOD, 1861–63.—Professor WILLIAM THOMSON, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19TH BIENNIAL PERIOD, 1863–65.—Principal FORBES, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society.

20TH BIENNIAL PERIOD, 1865–67.—Professor C. PIAZZI SMYTH, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21ST BIENNIAL PERIOD, 1867–69.—Professor P. G. TAIT, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22ND BIENNIAL PERIOD, 1869–71.—Professor CLERK MAXWELL, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23RD BIENNIAL PERIOD, 1871–73.—Professor P. G. TAIT, for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24TH BIENNIAL PERIOD, 1873–75.—Professor CRUM BROWN, for his Researches "on the Sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25TH BIENNIAL PERIOD, 1875–77.—Professor M. FORSTER HEDDLE, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26TH BIENNIAL PERIOD, 1877–79.—Professor H. C. FLEEMING JENKIN, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II. having appeared in the volume for 1877–78.

27TH BIENNIAL PERIOD, 1879–81.—Professor GEORGE CHRYSTAL, for his paper "on the Differential Telephone," published in the Transactions of the Society.

28TH BIENNIAL PERIOD, 1881–83.—THOMAS MUIR, Esq., LL.D., for his "Researches into the Theory of Determinants and Continued Fractions," published in the Proceedings of the Society.

29TH BIENNIAL PERIOD, 1883–85.—JOHN AITKEN, Esq., for his paper "on the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena, published in the Transactions of the Society.

30TH BIENNIAL PERIOD, 1885–87.—JOHN YOUNG BUCHANAN, Esq., for a series of Communications, extending over several years, on subjects connected with Ocean Circulation, Compressibility of Glass, &c.; two of which, viz., "On Ice and Brines," and "On the Distribution of Temperature in the Antarctic Ocean," have been published in the Proceedings of the Society.

31ST BIENNIAL PERIOD, 1887–89.—Professor E. A. LETTS, for his papers on the Organic Compounds of Phosphorus, published in the Transactions of the Society.

32ND BIENNIAL PERIOD, 1889–91.—R. T. OMOND, Esq., for his Contributions to Meteorological Science, many of which are contained in Vol. XXXIV. of the Society's Transactions.

33RD BIENNIAL PERIOD, 1891-93.—Professor THOMAS R. FRASER, F.R.S., for his papers on *Strophanthus hispidus*, Strophanthin, and Strophanthidin, read to the Society in February and June 1889 and in December 1891, and printed in Vols. XXXV., XXXVI., and XXXVII. of the Society's Transactions.

34TH BIENNIAL PERIOD, 1893–95.—Dr CARGILL G. KNOTT, for his papers on the Strains produced by Magnetism in Iron and in Nickel, which have appeared in the Transactions and Proceedings of the Society.

35TH BIENNIAL PERIOD, 1895–97.—Dr THOMAS MUIR, for his continued Communications on Determinants and Allied Questions.

36TH BIENNIAL PERIOD, 1897–99.—Dr JAMES BURGESS, for his paper "on the Definite Integral $\frac{2}{\sqrt{\pi}}\int_0^t \epsilon^{-v} dt$, with extended Tables of Values," printed in Vol. XXXIX. of the Transactions of the Society.

37TH BIENNIAL PERIOD, 1899–1901.—Dr HUGH MARSHALL, for his discovery of the Persulphates, and for his Communications on the Properties and Reactions of these Salts, published in the Proceedings of the Society.

38TH BIENNIAL PERIOD, 1901–03.—Sir WILLIAM TURNER, K.C.B., LL.D., F.R.S., &c., for his memoirs entitled "A Contribution to the Craniology of the People of Scotland," published in the Transactions of the Society, and for his "Contributions to the Craniology of the People of the Empire of India," Parts I., II., likewise published in the Transactions of the Society.

39TH BIENNIAL PERIOD, 1903–05.—THOMAS H. BRYCE, M.A., M.D., for his two papers on "The Histology of the Blood of the Larva of *Lepidosiren paradoxa*," published in the Transactions of the Society within the period.

II. MAKDOUGALL-BRISBANE PRIZE.

1ST BIENNIAL PERIOD, 1859.—Sir RODERICK IMPEY MURCHISON, on account of his Contributions to the Geology of Scotland.

2ND BIENNIAL PERIOD, 1860–62.—WILLIAM SELLER, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3RD BIENNIAL PERIOD, 1862–64.—JOHN DENIS MACDONALD, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4TH BIENNIAL PERIOD, 1864–66.—Not awarded.

5TH BIENNIAL PERIOD, 1866–68.—Dr ALEXANDER CRUM BROWN and Dr THOMAS RICHARD FRASER, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6TH BIENNIAL PERIOD, 1868–70.—Not awarded.

7TH BIENNIAL PERIOD, 1870–72.—GEORGE JAMES ALLMAN, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8TH BIENNIAL PERIOD, 1872–74.—Professor LISTER, for his paper "on the Germ Theory of Putrefaction and the Fermentive Changes," communicated to the Society, 7th April 1873.

9TH BIENNIAL PERIOD, 1874–76.—ALEXANDER BUCHAN, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10TH BIENNIAL PERIOD, 1876–78.—Professor ARCHIBALD GEIKIE, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

11TH BIENNIAL PERIOD, 1878–80.—Professor PIAZZI SMYTH, Astronomer-Royal for Scotland, for his paper "on the Solar Spectrum in 1877–78, with some Practical Idea of its probable Temperature of Origination," published in the Transactions of the Society.

12TH BIENNIAL PERIOD, 1880–82.—Professor JAMES GEIKIE, for his "Contributions to the Geology of the North-West of Europe," including his paper "on the Geology of the Faroes," published in the Transactions of the Society.

13TH BIENNIAL PERIOD, 1882–84.—EDWARD SANG, Esq., LL.D., for his paper "on the Need of Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor," and generally for his Recalculation of Logarithms both of Numbers and Trigonometrical Ratios, —the former communication being published in the Proceedings of the Society.

14TH BIENNIAL PERIOD, 1884–86.—JOHN MURRAY, Esq., LL.D., for his papers "On the Drainage Areas of Continents, and Ocean Deposits," "The Rainfall of the Globe, and Discharge of Rivers," "The Height of the Land and Depth of the Ocean," and "The Distribution of Temperature in the Scottish Lochs as affected by the Wind."

15TH BIENNIAL PERIOD, 1886–88.—ARCHIBALD GEIKIE, Esq., LL.D., for numerous Communications, especially that entitled "History of Volcanic Action during the Tertiary Period in the British Isles," published in the Transactions of the Society.

16TH BIENNIAL PERIOD, 1888–90.—Dr LUDWIG BECKER, for his paper on "The Solar Spectrum at Medium and Low Altitudes," printed in Vol. XXXVI. Part I. of the Society's Transactions.

17TH BIENNIAL PERIOD, 1890–92.—HUGH ROBERT MILL, Esq., D.Sc., for his papers on "The Physical Conditions of the Clyde Sea Area," Part I. being already published in Vol. XXXVI. of the Society's Transactions.

18TH BIENNIAL PERIOD, 1892–94.—Professor JAMES WALKER, D.Sc., Ph.D., for his work on Physical Chemistry, part of which has been published in the Proceedings of the Society, Vol. XX. pp. 255–263. In making this award, the Council took into consideration the work done by Professor Walker along with Professor Crum Brown on the Electrolytic Synthesis of Dibasic Acids, published in the Transactions of the Society.

19TH BIENNIAL PERIOD, 1894–96.—Professor JOHN G. M'KENDRICK, for numerous Physiological papers, especially in connection with Sound; many of which have appeared in the Society's publications.

20TH BIENNIAL PERIOD, 1896–98.—Dr WILLIAM PEDDIE, for his papers on the Torsional Rigidity of Wires.

21ST BIENNIAL PERIOD, 1898–1900.—Dr RAMSAY H. TRAQUAIR, for his paper entitled "Report on Fossil Fishes collected by the Geological Survey in the Upper Silurian Rocks of Scotland," printed in Vol. XXXIX. of the Transactions of the Society.

22ND BIENNIAL PERIOD, 1900–02.—Dr ARTHUR T. MASTERMAN, for his paper entitled "The Early Development of *Cribrella oculata* (Forbes), with remarks on Echinoderm Development," printed in Vol. XL. of the Transactions of the Society.

23RD BIENNIAL PERIOD, 1902–04.—Mr JOHN DOUGALL, M.A., for his paper on "An Analytical Theory of the Equilibrium of an Isotropic Elastic Plate," published in Vol. XLI. of the Transactions of the Society.

24TH BIENNIAL PERIOD, 1904–06.—JACOB E. HALM, Ph.D., for his two papers entitled "Spectroscopic Observations of the Rotation of the Sun," and "Some Further Results obtained with the Spectroheliometer," and for other astronomical and mathematical papers published in the Transactions and Proceedings of the Society within the period.

III. THE NEILL PRIZE.

1st Triennial Period, 1856–59.—Dr W. Lauder Lindsay, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2nd Triennial Period, 1859–62.—Robert Kaye Greville, LL.D., for his Contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3rd Triennial Period, 1862–65.—Andrew Crombie Ramsay, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geographical Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4th Triennial Period, 1865–68.—Dr William Carmichael M'Intosh, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5th Triennial Period, 1868–71.—Professor William Turner, for his papers "on the great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6th Triennial Period, 1871–74.—Charles William Peach, Esq., for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7th Triennial Period, 1874–77.—Dr Ramsay H. Traquair, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton)," published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

8th Triennial Period, 1877–80.—John Murray, Esq., for his paper "on the Structure and Origin of Coral Reefs and Islands," published (in abstract) in the Proceedings of the Society.

9th Triennial Period, 1880–83.—Professor Herdman, for his papers "on the Tunicata," published in the Proceedings and Transactions of the Society.

10th Triennial Period, 1883–86.—B. N. Peach, Esq., for his Contributions to the Geology and Palæontology of Scotland, published in the Transactions of the Society.

11th Triennial Period, 1886–89.—Robert Kidston, Esq., for his Researches in Fossil Botany, published in the Transactions of the Society.

12th Triennial Period, 1889–92.—John Horne, Esq., F.G.S., for his Investigations into the Geological Structure and Petrology of the North-West Highlands.

13th Triennial Period, 1892–95.—Robert Irvine, Esq., for his papers on the action of Organisms in the Secretion of Carbonate of Lime and Silica, and on the solution of these substances in Organic Juices. These are printed in the Society's Transactions and Proceedings.

14th Triennial Period, 1895–98.—Professor Cossar Ewart, for his recent Investigations connected with Telegony.

15th Triennial Period, 1898–1901.—Dr John S. Flett, for his papers entitled "The Old Red Sandstone of the Orkneys" and "The Trap Dykes of the Orkneys," printed in Vol. XXXIX. of the Transactions of the Society.

16th Triennial Period, 1901–04.—Professor J. Graham Kerr, M.A., for his Researches on *Lepidosiren paradoxa*, published in the Philosophical Transactions of the Royal Society, London.

IV. GUNNING VICTORIA JUBILEE PRIZE.

1st Triennial Period, 1884–87.—Sir William Thomson, Pres. R.S.E., F.R.S., for a remarkable series of papers "on Hydrokinetics," especially on Waves and Vortices, which have been communicated to the Society.

2nd Triennial Period, 1887–90.—Professor P. G. Tait, Sec. R.S.E., for his work in connection with the "Challenger" Expedition, and his other Researches in Physical Science.

3rd Triennial Period, 1890–93.—Alexander Buchan, Esq., LL.D., for his varied, extensive, and extremely important Contributions to Meteorology, many of which have appeared in the Society's Publications.

4th Triennial Period, 1893–96.—John Aitken, Esq., for his brilliant Investigations in Physics, especially in connection with the Formation and Condensation of Aqueous Vapour.

1st Quadrennial Period, 1896–1900.—Dr T. D. Anderson, for his discoveries of New and Variable Stars.

2nd Quadrennial Period, 1900–04.—Sir James Dewar, LL.D., D.C.L., F.R.S., &c., for his researches on the Liquefaction of Gases, extending over the last quarter of a century, and on the Chemical and Physical Properties of Substances at Low Temperatures: his earliest papers being published in the Transactions and Proceedings of the Society.

PROCEEDINGS

OF THE

STATUTORY GENERAL MEETINGS,

23RD OCTOBER 1905,

22ND OCTOBER 1906,

AND OF A

SPECIAL GENERAL MEETING,

21ST DECEMBER 1906.

STATUTORY MEETING.

HUNDRED AND TWENTY-THIRD SESSION.

Monday, 23*rd October* 1905.

At the Annual Statutory Meeting,

The Hon. Lord M'LAREN, LL.D., Vice-President, in the Chair,

The Minutes of last Annual Statutory Meeting of 24th October 1904 were read, approved, and signed.

On the motion of Dr HORNE, Dr B. N. PEACH and Dr R. M. FERGUSON were appointed Scrutineers, and the Ballot for the New Council commenced.

The TREASURER'S Accounts were submitted, along with the Auditors' Report, and approved.

The Scrutineers reported that the following New Council had been duly elected:—

The Right Hon. Lord KELVIN, G.C.V.O., LL.D., D.C.L., F.R.S., President.
The Hon. Lord M'LAREN, LL.D.,
The Rev. Professor FLINT, D.D.,
ROBERT MUNRO, M.A., M.D., LL.D.,
Sir JOHN MURRAY, K.C.B., LL.D., F.R.S.,
RAMSAY H. TRAQUAIR, M.D., LL.D., F.R.S.,
Professor CRUM BROWN, M.D., LL.D.,
} Vice-Presidents.
Professor GEORGE CHRYSTAL, LL.D., General Secretary.
Professor D. J. CUNNINGHAM, M.D., LL.D., F.R.S.,
CARGILL G. KNOTT, D.Sc.
} Secretaries to Ordinary Meetings.
PHILIP R. D. MACLAGAN, F.F.A., Treasurer.
ALEX. BUCHAN, M.A., LL.D., F.R.S., Curator of Library and Museum.

COUNCILLORS.

Professor ANDREW GRAY, M.A., LL.D., F.R.S.	LEONARD DOBBIN, Ph.D.
ROBERT KIDSTON, F.R.S., F.G.S.	Professor J. C. EWART, M.D., F.R.S.
D. NOËL PATON, M.D., F.R.C.P.E.	B. N. PEACH, LL.D., F.R.S.
Professor JOHN CHIENE, C.B., M.D., LL.D.	JAMES J. DOBBIE, D.Sc., F.R.S.
Professor J. GRAHAM KERR, M.A.	Professor GEORGE A. GIBSON, M.A., LL.D.
WILLIAM PEDDIE, D.Sc.	Professor J. P. KUENEN, Ph.D.

On the motion of Lord M'LAREN, thanks were voted to the Treasurer.

On the motion of Dr HORNE, thanks were voted to the Auditors, who were reappointed.

On the motion of Professor CRUM BROWN, thanks were voted to the Scrutineers.

On the motion of Dr MUNRO, thanks were voted to the General Secretary, and on the motion of Mr A. SCOTT IRELAND, thanks were voted to the Chairman.

ROBERT MUNRO, *V.P.*,

Chairman.

STATUTORY MEETING.

HUNDRED AND TWENTY-FOURTH SESSION.

Monday, 22*nd October* 1906.

At the Annual Statutory Meeting,

Dr ROBERT MUNRO in the Chair,

The Minutes of last Annual Statutory Meeting of 23rd October 1905 were read, approved, and signed.

On the motion of Dr JAMES BURGESS, seconded by Dr PEACH, Professor JOHN GIBSON and Dr T. N. JOHNSTON were appointed Scrutineers, and the Ballot for the New Council commenced.

The SECRETARY laid on the table the TREASURER'S Accounts for the past year. These, with the Auditors' Report, were read and approved.

Dr CRUM BROWN made a sympathetic reference to the late Treasurer, and moved the following expression of sympathy with his family, seconded by Dr BURGESS:—

> "That the Fellows of the Royal Society at this their Stated Meeting desire to express the deep regret which they feel at the death of the Treasurer, Mr PHILIP R. D. MACLAGAN, and at the same time to acknowledge their deep indebtedness to Mr MACLAGAN for the great service he has for many years rendered the Society."

It was further resolved that a copy of this resolution be forwarded to Mrs MACLAGAN, with an expression of the Society's deep sympathy with her in her loss.

The Scrutineers reported that the following New Council had been duly elected :—

The Right Hon. Lord KELVIN, G.C.V.O., LL.D., D.C.L., F.R.S., President.
The Rev. Professor FLINT, D.D.,
ROBERT MUNRO, M.A., M.D., LL.D.,
Professor ANDREW GRAY, M.A., LL.D., F.R.S.,
RAMSAY H. TRAQUAIR, M.D., LL.D., F.R.S.,
Professor CRUM BROWN, M.D., LL.D., F.R.S.,
ALEXANDER BUCHAN, M.A., LL.D., F.R.S.,
} Vice-Presidents.
Professor GEORGE CHRYSTAL, LL.D., General Secretary.
Professor D. J. CUNNINGHAM, M.D., LL.D., F.R.S.,
CARGILL G. KNOTT, D.Sc.,
} Secretaries to Ordinary Meetings.
JAMES CURRIE, M.A., Treasurer.
JOHN S. BLACK, M.A., LL.D., Curator of Library and Museum.

COUNCILLORS.

Professor J. GRAHAM KERR, M.A.
WILLIAM PEDDIE, D.Sc.
LEONARD DOBBIN, Ph.D.
Professor J. C. EWART, M.D., F.R.S.
B. N. PEACH, LL.D., F.R.S., F.G.S.
JAMES J. DOBBIE, M.A., D.Sc., F.R.S.
Professor GEORGE A. GIBSON, M.A., LL.D.
Professor J. P. KUENEN, Ph.D.
Professor J. ARTHUR THOMSON, M.A.
JOHN HORNE, LL.D., F.R.S., F.G.S.
Professor E. A. SCHÄFER, LL.D., F.R.S.
The Hon. LORD M'LAREN, LL.D.

On the motion of Professor CUNNINGHAM, seconded by Dr DOBBIE, thanks were voted to the Scrutineers.

On the motion of Professor CRUM BROWN, seconded by Professor CHRYSTAL, thanks were voted to the Auditors, who were reappointed; and on the motion of the CHAIRMAN, thanks were voted to the General Secretary.

On the motion of Dr BURGESS, seconded by Dr PEACH, thanks were voted to the Chairman.

ROBERT MUNRO, *V.P.*,
Chairman.

SPECIAL GENERAL MEETING.

21*st December* 1906.

At a Special General Meeting,

Dr ROBERT MUNRO, Vice-President, in the Chair,

On the request of the CHAIRMAN, the GENERAL SECRETARY read the instruction by the Council to call a General Meeting of the Society to consider a Report on negotiations with the Secretary for Scotland regarding new accommodation for the Society.

The GENERAL SECRETARY then read the Report by the Council regarding new accommodation to be provided for the Society in consequence of its proposed removal from the Royal Institution, under the provisions of the "National Galleries (Scotland) Bill"; and regarding a proposed additional Parliamentary Grant for the Scientific Purposes of the Society.

Sir WM. TURNER moved that the Society receive the Report of the Council, and approve of it.

Professor BOWER seconded.

The motion, on being put to the Meeting by the Chairman, was carried unanimously.

ROBERT MUNRO, *V.P.*

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